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IITRI-B6092-13
(Final Report)

# A STUDY OF OPTIMUM METHODS FOR PREPARING ALUMINUM SURFACES FOR WELDING

National Aeronautics
and Space Administration
George C. Marshall Space Flight Center
Alabama 35812

Contract No. NAS8-21354

IIT RESEARCH INSTITUTE
Technology Center
Chicago, Illinois 60616

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June 13, 1968 to July 13, 1969

for

National Aeronautics and Space Administration
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July 10, 1969

# FOREWORD

This is Report No. IITRI-B6092-13 (Final Report) of IITRI Project B6092 under Contract No. NAS8-21354, entitled "A Study of Optimum Methods for Preparing Aluminum Surfaces for Welding." The report summarizes the work performed during the period from June 13, 1968, to July 13, 1969.

Personnel who contributed to this program include F. C. Holtz, Metallurgical Advisor; R. E. Beal, Research Metallurgist; J. S. Dolega, Experimentalist; T. M. Scopelite, Manager, Mechanical Systems; W. F. Ridenour, Research Engineer; C. F. Lamber, Associate Research Engineer; and G. E. Faulkner, Manager, Welding Research.

Data for the report are recorded in IITRI Logbooks C18705, C18943, and C18706.

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# A STUDY OF OPTIMUM METHODS FOR PREPARING ALUMINUM SURFACES FOR WELDING


## ABSTRACT

Research was performed to develop and demonstrate practical techniques for preparing the weld surfaces of aluminum components. Two techniques were evaluated: dry machining as the primary cleaning method and electrical discharge cleaning as a supplemental method for use if dry machined surfaces were subsequently contaminated. Dry machining proved practical and a prototype device, which was based on this method, was designed and fabricated. Electrical discharge cleaning proved unacceptable under the conditions employed in the program.

The prototype device was designed to prepare the abutting edges and two adjacent surfaces simultaneously utilizing dry machining in the face-milling mode. Evaluations of the device showed it to be: (1) practical; (2) capable of preparing surfaces with a low defect potential; (3) adaptable to components of varying size and configuration; and, (4) capable of maintaining the dimensional tolerances required in advanced aerospace structures.

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## I. INTRODUCTION

The objectives of this research program were to develop and demonstrate practical techniques for preparing the weld surfaces of aluminum components. The aim is to minimize surface contamination which contributes to porosity and nonmetallic inclusions in weldments on space vehicle tankage and assemblies. In previous NASA research it was shown that contamination of weld surfaces contributes significantly to weld defects. It was also found that currently used practices, such as chemical cleaning followed by wire brushing and/or scraping, cannot be relied on to produce surfaces with minimum defect potential.

This program was undertaken to develop new techniques and construct a prototype device for preparing weld surfaces with lower defect potential than can be achieved with current practices. To achieve these objectives, a three-phase program was performed. The objectives for each phase follow:

Phase I - Conceptual study to evaluate and select surface preparation techniques and systems.

Phase II - Design and fabrication study to develop and fabricate a prototype device for weld surface preparation of aluminum components.

Phase III - Evaluation study to provide an empirical evaluation of surfaces prepared with the prototype device.

The basic concept for the system was to remove contaminated surface layers from weld surfaces and completed parts. Therefore, all parts must be final machined with reasonably smooth surfaces prior to the surface preparation operation. A number of requirements were developed for the surface preparation methods. Of

course, the most important is that the technique provide surfaces with low defect potential. Other requirements are as follows:

(1) Surfaces must include the abutting edges of the weld grooves and 25.4 mm (1 in.) widths on the adjoining surfaces.

(2) Weld edges must be on cylinders (longitudinal and circumferential surfaces) and on elliptical and hemispherical domes; welds must be in vertical, horizontal, and inclined curved positions and in combinations of these positions.

(3) Groove geometry must include all standard configurations including square grooves, single V-grooves, double V-grooves, and single U-grooves.

(4) Depth of metal removal will be a minimum of 0.127 mm (0.005 in.).

(5) The finished surface roughness will be a maximum of 5.08 μm (200 μin.) and have a minimum of smeared metal.

(6) Thicknesses of the aluminum material should be in the range of 2.54 mm (0.100 in.) to 25.4 mm (1.00 in.).

(7) No lubricants nor any manual work will be permitted.

(8) Other geometrical characteristics will be those that permit the best welding practices--i.e., minimum waviness of edge; absence of burrs; no burning, no discoloration or contamination of surfaces; and no gouges, grooves, nicks, or undercuts.

The results achieved in the program are discussed in subsequent sections of the report. To facilitate discussion, the results are presented to conform to the three phases of the program.

## II. PHASE I - CONCEPTUAL STUDY

The objectives of Phase I were to: (1) evaluate surface cleaning methods; (2) evaluate surface cleaning systems; and (3) select cleaning techniques and develop design concepts for the prototype device.

Two techniques were investigated for preparing aluminum weld surfaces: mechanical cleaning and electric discharge cleaning. Primary emphasis was on mechanical cleaning, since the effectiveness of this method was established in a previous NASA program.[1] Electrical discharge cleaning was evaluated as a supplementary method to be used only if the mechanically cleaned surfaces were accidentally contaminated or exposed to a humid atmosphere for a considerable time after cleaning. Under these conditions a second mechanical preparation step might not be permissible because of dimensional tolerance limits (e.g., minimum thickness or gap); consequently, an electrical discharge desorption treatment could be advantageous for restoring the surface. If effective, the electrical discharge desorption treatment would employ either the same power supply and torch used for welding, or an auxiliary power supply and electrode system would be used to achieve the proper electric discharge conditions.

## A. Experimental Procedures

Surface preparation techniques were evaluated by preparing the surfaces of small specimens, then determining the quality and defect potential of the cleaned surfaces. The specimens, prepared from 6.35 mm (1/4 in.) thick 2014-T6 aluminum alloy plate, were nominally 304.8 mm (12 in.) long and 25.4 mm (1 in.) wide; the 25.4 x 304.8 mm (1 x 12 in.) surfaces of the plates were cleaned.

Several techniques were used to evaluate the cleaned surfaces: visual examination, light microscopy, Proficorder measurements, scanning electron microscopy, and horizontal fusion spot-weld tests. The visual and light microscopy examinations provided preliminary data of weld surface quality; the Proficorder measurements were performed to determine surface roughness. The two most useful techniques for studying surface preparation methods are scanning electron microscopy and the horizontal fusion spot-weld test.

The scanning electron microscope (SEM), an electronoptic device which permits direct viewing of a surface, produces images

similar to those obtained with light microscopy but higher magnifications, a much greater depth of focus, and better resolution are obtained. Thus, this instrument is particularly well suited to the examination of fine surface details. To provide specimens for SEM examination, samples approximately 9.5 $mm^2$ (3/8 in.) were carefully removed from the cleaned surfaces.

The horizontal fusion spot-weld test is extremely sensitive to the surface quality of aluminum. Test preparations involved placing the cleaned surfaces of two specimens (as shown schematically in Figure 1) and fusing a spot weld. The weld is cnetered on the interface using the gas tungsten-arc welding process. The test piece is then fractured at the interface, and the weld nugget on each piece examined for evidence of weld defects.

The fusion spot-weld test setup is shown in Figure 2. The samples to be evaluated are positioned in a vise between two heavy pieces of 1100 aluminum so that the 304.8 mm (12 in.) lengths are forward. The large pieces of aluminum serve as a heat sink. The spot welds are made with the DCSP/TIG process using the following settings with a Sciaky S-4 power supply: constant current mode; arc current, 280 and 320 amps; arc voltage, 18 volts; arc length, 1.59 mm (1/16 in.); gas, high-purity helium (<10 ppm $H_2O$); arc duration, 2 sec; gas preflow, 1 min; gas flow, 0.283 $mm^3$/hr (100 cfh); electrode, tungsten-2% thoria, 3.97 mm (5/32 in.) diameter; and tip geometry, 32° taper, 2.37 mm (3/32 in.) blunted tip.

The test is extremely sensitive to the properties of the abutting surfaces. The gases liberated from the surfaces by the heat of the arc are trapped by solid contact along the fusion line. The pressure of the gases generated at the melting front is a function of the amount of surface contamination. At some level of contamination, sufficient pressure is built up to cause the gases to escape into the weld pool. Porosity is formed by the ejection of the dissolved gases during solidification and cooling. Heavily contaminated surfaces exhibit porosity throughout the weld fusion zone, whereas cleaner surfaces are characterized by porosity only

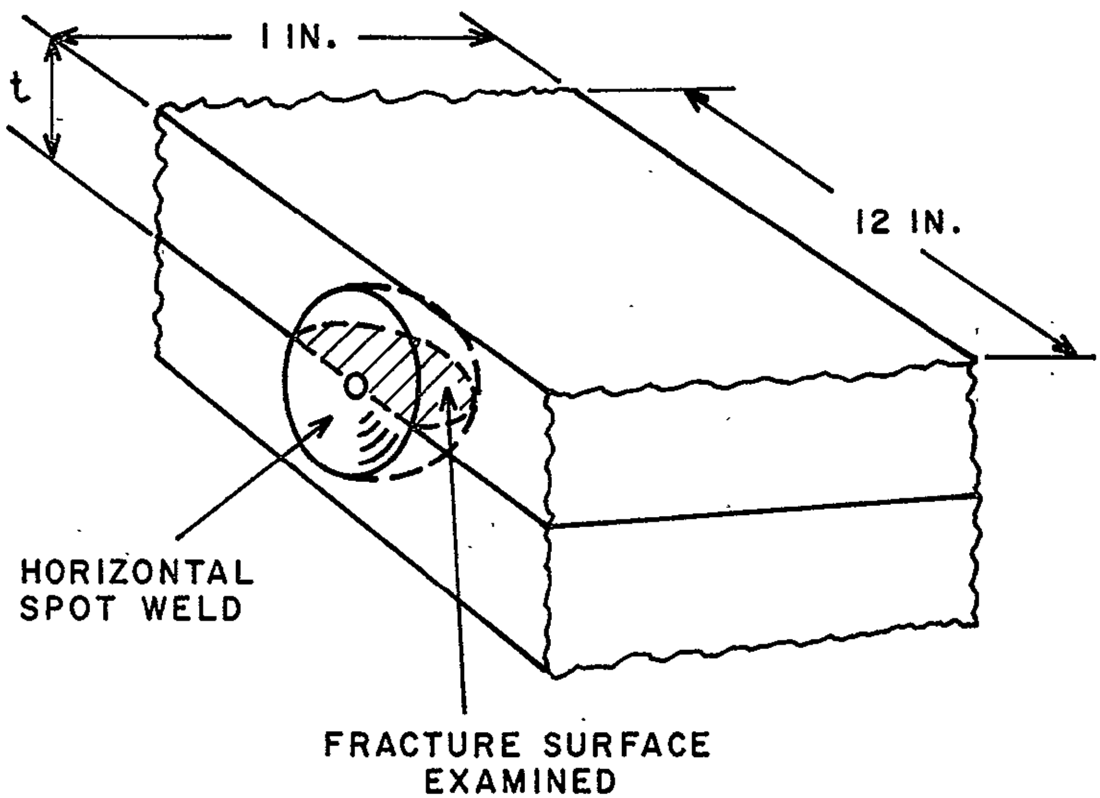


Fig. 1 - Schematic Illustration of Horizontal Fusion Spot-Weld Test.

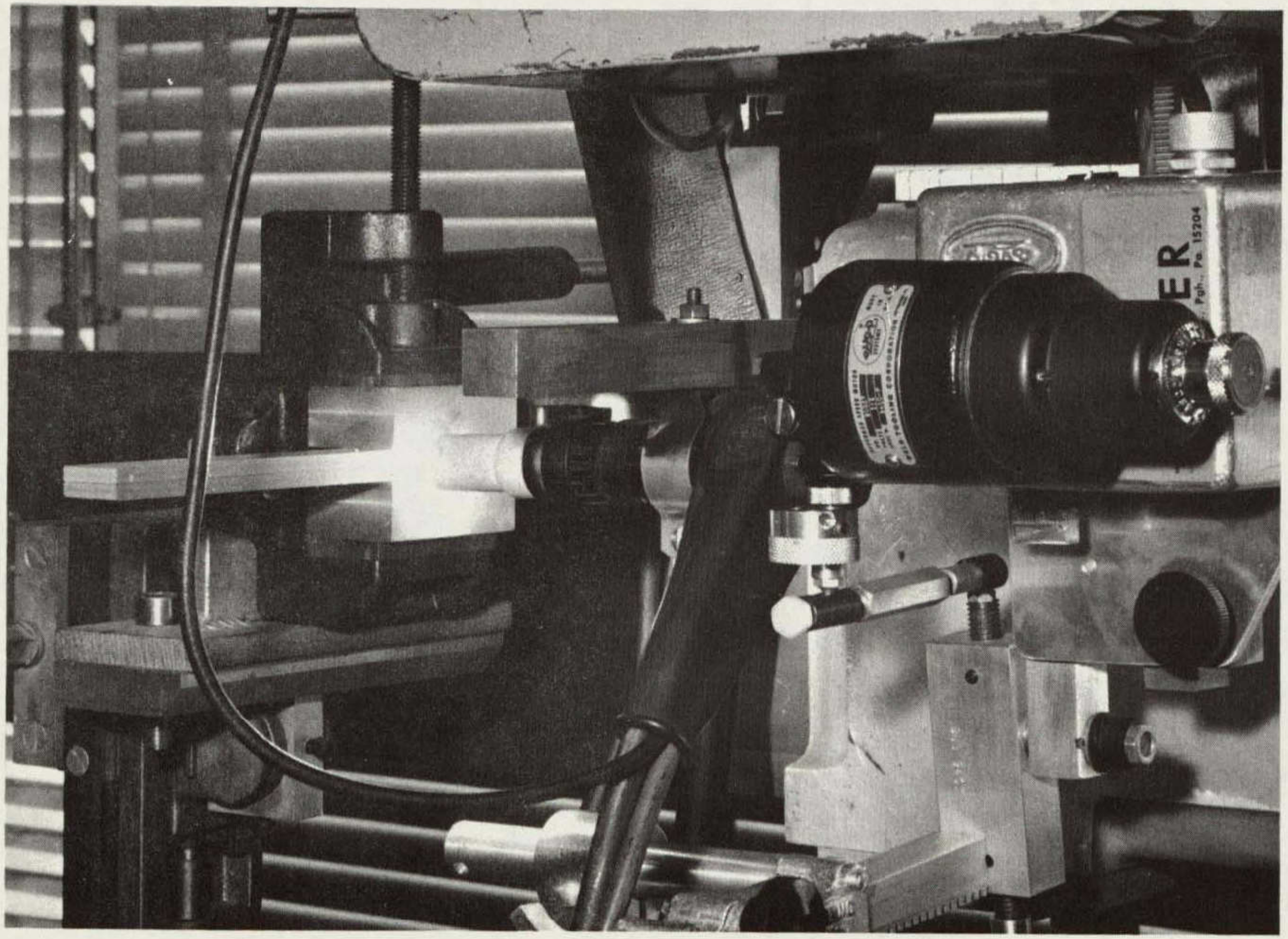

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Fig. 2 - Fusion Spot-Weld Test in Progress.

along the fusion line or by the complete absence of porosity. The amount of oxide film present on the surfaces determines the fusibility and depth of penetration along the interface. Oxide inclusions are readily discerned on the parted surfaces, at the fusion line, and in the weld.

The degree and location of defects in the spot weld nugget were examined by fracturing the pieces through the weld area thereby exposing the interface, fusion line, and fused weld metal. Defect content was determined by optical inspection of the fracture weld at 25X magnification.

## B. Results and Discussion

Data from past research[(1)] provided the basis upon which mechanical and electric discharge methods were selected for evaluation. Considerable information was available about the characteristics of mechanically cleaned surfaces. Therefore, efforts on mechanically cleaned surfaces were directed primarily to the selection of drive motors and cutters and to the design concept of a mechanical cleaning system. Only limited data were available on the characteristics of surfaces cleaned by electric discharge methods and on techniques which produce the most desirable surfaces. Consequently, evaluations of electric discharge cleaning methods were directed primarily toward determining surface characteristics and cleaning techniques.

### 1. Mechanical Cleaning Methods

Past work has shown that an undercutting machine operation, such as face-milling without a coolant, can provide aluminum surfaces with a very low defect potential. These surfaces are ordinarily characterized by the normal surface irregularities (such as tears, pits, waves, and scratches) observed on machined surfaces, and they have a naturally formed hydrated oxide layer of approximately 100 A or less in thickness. Surfaces that are face milled to a 1.27 to 5.08 mm (50 to 200 $\mu$in.) rms finish in an ambient air atmosphere (70°F and 50-60% RH) contain about 0.01 to 0.05 mg/cm$^2$

of water in the hydrated oxide. This level of contamination alone does not usually result in significant weld defects and, from a practical standpoint, a dry machined surface represents the best condition for welding.

Aluminum alloys are comparatively easy to machine, and the cutting forces required for chip removal operations are generally lower than those for other structural materials at similar hardness or strength levels. Machining operations such as turning or milling can be carried out at speeds well in excess of 304.8 m/min (1000 fpm); conventional cemented carbide tool materials have very long tool lives at these high speeds. Good surface finish and dimensional control are also readily obtainable under proper machining conditions.

The major disadvantage of the mechanical cleaning methods is that metal must be removed to expose clean surfaces. Thus, multiple cleaning operations may not be possible because of dimensional tolerance requirements in the components being welded. Therefore, precautions must be taken to minimize contamination after the final mechanical cleaning operation is performed to eliminate the need for additional cleaning.

a. Preliminary Studies

Preliminary studies of mechanical cleaning methods were performed to evaluate lightweight motors for driving milling cutters, to evaluate cutter types and designs, and to select a cutting mode. With one exception, the drive motors were vertically mounted on a bracket fastened to the spindle of a Boyar-Schultz surface grinder. Test cuts were taken on the surfaces of the specimens, which were attached to the bed of the grinder. Depth of cut was varied between 0.051 and 0.51 mm (0.002 and 0.020 in.) and the width of cut, with one exception, was maintained constant at 18.05 mm (3/4 in.). Cutting speed was varied between 152.4 and 3048 mm/min (6 and 120 ipm).

A number of air motors were evaluated in the preliminary studies. Air motors were selected because they were considered to provide an optimum combination of high speed, high torque, and light weight. Each motor was evaluated in the climb-milling mode on the basis of its power to complete a dry cut of maximum dimensions, its size and weight (adaptability for use on a portable lightweight device), and its low potential for contaminating the workpiece with air from the motor spindle.

The air motors that were evaluated are listed in Table I. Except for the Model FND reciprocating machine, which was fed manually, all motors were attached to the spindle of the surface grinder for test evaluations. Another exception was the Model HSL motor which was used to cut only 6.35 mm (1/4 in.) width; all other motors were evaluated for their capacity to cut a 18.05 mm (3/4 in.) wide surface.

The four ARO Corporation motors developed adequate power to produce the required cut. However, the 17,000 and 18,000 rpm units produced superior surface finishes compared to those produced with the 4,500 rpm motors. These results, summarized in Table II, demonstrate the suitability of the 0.3 and 0.9 hp ARO Corporation motors. The higher speed units produced superior surface finishes. A multiflute end-mill or burr-type cutter also produced a superior surface compared to the four-flute tool.

No other motor was considered acceptable for the preparation of aluminum surfaces within the requirements of the program. The PCB III motor, running at 75,000 rpm and using a 6.35 mm (1/4 in.) diameter four-flute end mill did not provide sufficient torque to make a 0.0508 mm (0.002 in.) deep cut at 304.8 mm/min (12 in/min) feed. The surface finish produced by climb milling was 0.76-2.28 μm (30-90 μin.). The chips were thin, fiber-like splinters approximately 5/16 in. long. This motor was not tested any further as it could not develop sufficient torque to complete a maximum cut. Inadequate torque also characterized the Model HSL Hyprez rotary unit, and it was eliminated from further testing. With the reciprocating

TABLE I

AIR MOTORS EVALUATED

| Supplier | Motor and Description |
| --- | --- |
| Metal Removal Co. | Model PCB III high speed turbine drive drilling spindle. 75,000 rpm |
| ARO Corporation | 2200 Series, 7801-2, 0.9 hp, 4500 rpm mill motor |
| | 7142-D, 0.3 hp, 4500 rpm motor |
| | 2200 Series, 7801-2, 0.9 hp, 18,000 rpm mill motor |
| | 7487 (Series 0) 0.3 hp, 17,000 rpm motor |
| Engis Equipment Co. | Model HSL Hyprez rotary, air operated hand piece, 5,000 to 35,000 rpm |
| | Model FND Hyprez reciprocating machine, variable speed control to 100 strokes/min |

TABLE II

SURFACE FINISHES PRODUCED WITH ARO MOTORS UNDER CLIMB MILLING CONDITIONS

| Depth of Cut mm | Depth of Cut (in.) | Carbide Milling Cutter* | Feed mm/min | Feed (ipm) | Approximate Surface Finish μm | Approximate Surface Finish (μin.) |
|---|---|---|---|---|---|---|
| | | **7801-2: 0.9 hp, 4500 rpm** | | | | |
| 0.127 | (0.005) | 4 flute | 304.8 | (12) | ≈3.18 | (≈125) |
| 0.127 | (0.005) | 4 flute | 761.0 | (30) | ≈12.7 | (≈500) |
| 0.127 | (0.005) | 1 flute | 304.8 | (12) | ≈5.08 | (≈200) |
| 0.254 | (0.010) | 4 flute | 152.4 | ( 6) | ≈3.18 | (≈125) |
| | | **7142-D: 0.3 hp, 4500 rpm** | | | | |
| 0.127 | (0.005) | 4 flute | 508.0 | (20) | ≈12.7 | (≈500) |
| 0.508 | (0.020) | 4 flute | 304.8 | (12) | ≈17.8 | (≈700) |
| | | **7801-2: 0.9 hp, 18,000 rpm** | | | | |
| 0.127 | (0.005) | 4 flute | 304.8 | (12) | 2.54-3.18 | (100-125) |
| 0.127 | (0.005) | 4 flute | 508.0 | (20) | ≈2.54 | (≈100) |
| 0.254 | (0.010) | 4 flute | 508.0 | (20) | ≈3.18 | (≈125) |
| 0.127 | (0.005) | Multiflute | 508.0 | (20) | 1.6-2.54 | (63-100) |
| 0.127 | (0.005) | Burr (coarse) | 508.0 | (20) | 1.27-2.54 | (50-100) |
| 0.127 | (0.005) | Burr (coarse) | 254.0 | (10) | 0.82-1.6 | (32-63) |
| | | **7487: 0.3 hp, 17,000 rpm** | | | | |
| 0.127 | (0.005) | Multiflute | 913.4 | (36) | 0.76-1.27 | (30-50) |
| 0.0508 | (0.002) | Multiflute | 1826.8 | (72) | 1.77 | (70) |
| 0.0508 | (0.002) | Multiflute | 3048.0 | (120) | 5.08 | (200) |
| 0.127 | (0.005) | Multiflute | 2286.0 | (90) | 3.81 | (150) |
| 0.0508 | (0.002) | Burr | 2286.0 | (90) | 3.81 | (150) |
| 0.127 | (0.005) | Burr | 913.4 | (36) | 0.76-1.27 | (30-50) |
| 0.127 | (0.005) | Burr | 508.0 | (20) | 0.76 | (30) |
| 0.127 | (0.005) | Multiflute | 508.0 | (20) | 0.76-1.27 | (30-50) |

*All cutters were 6.35 mm (1/4 in.) diameter.

unit, surface quality was poor even when visually examined; tests with this unit also were terminated.

On the basis of these evaluations, three ARO Corporation motors were selected for use in evaluating the effects of cutting tool type, cutting tool geometry, and machining mode on surface quality:

1. 2200 Series, Model 7801-2, 2.42MJ (0.9 hp), 4500 rpm mill motor
2. 2200 Series, Model 7801-2, 2.42MJ (0.9 hp), 18,000 rpm mill motor
3. 7487 (Series 0), 0.81MJ (0.3 hp), 17,000 rpm motor.

A series of tests were performed with these air motors to evaluate their effectiveness under several cleaning conditions. For these evaluations the 2014-T6 aluminum alloy specimens were chemically cleaned for 1 min in 5 w/o NaOH at 180°-190°F, rinsed in demineralized water, agitated 15 sec in 50 v/o $HNO_3$ to remove smut, followed by a 1 min rinse in demineralized water to provide a surface with a high defect potential; the specimens were subsequently machined.

After machining, the prepared specimens were subjected to the fusion spot-weld test to evaluate surface quality. The surfaces were machined using combinations of the three motors, seven types of milling cutters, and three machining modes for the evaluation. A minimum of three fusion spot-weld tests were performed for each condition. The weld defect potential of each condition was determined by rating each surface of the fractured test pieces. Each spot weld was rated from 0 to 50: a rating of less than 5 represents a very low defect potential, values of 5 to 10 are acceptable, and ratings in excess of 10 are unacceptable.

Results from the fusion spot-weld tests are summarized in Table III and clearly show that face milling and climb milling produce acceptable surfaces on the basis of defect potential, whereas conventional milling under the conditions employed does

TABLE III

WELD-DEFECT POTENTIAL RATINGS FOR VARIOUS CUTTING CONDITIONS

| | Rating for Each Type of ARO Milling Motor | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2.42 MJ: 0.9 hp 4500 rpm | | | 2.42 MJ: 0.9 hp 18,000 rpm | | 0.81 MJ: 0.3 hp 17,000 rpm | |
| Type of Cutter | Climb | Conv. | Face | Climb | Conv. | Climb | Conv. |
| 1/2 in. Burr (carbide) | | 16 | | | | 10 | 12 |
| 1/4 in.-2F (carbide) | 14 | 45 | | 3 | 35 | 5 | 7 |
| 1/4 in.-4F (carbide) | 12 | 40 | | 5 | 13 | 4 | 20 |
| 1/4 in.-4F-LT (carbide) | 10 | 23 | | 2 | 27 | 4 | 10 |
| 3/8 in.-2F (carbide) | 8 | 25 | | 3 | 12 | | |
| 3/8 in.-4F (carbide) | 10 | 22 | | 5 | 18 | | |
| 1 1/4 in.-6F (HSS) | | | 1 | | | | |
| 1 1/2 in.-6F (HSS) | | | | | 1 | | |

Depth of cut ≅0.127 mm (0.005 in.)

Travel speed ≅814.4 mm/min (36 ipm)

not. This difference in weld defect potential is attributed to the mode of chip removal from the surface. In the face- and climb-milling modes, chips are removed cleanly from the surface as fine slivers; in the conventional milling mode, the chips drag over the surface and tend to become embedded rather than being cleanly cut away. The data in Table III also show that the higher cutting speeds, as represented by cutter diameter and drive motor speed, resulted in surfaces with the best defect potential ratings.

This preliminary study provided a basis for developing a mechanical surface preparation system; the important results are summarized below:

1. The ARO Corporation motors provide sufficient torque and cutting speed to prepare aluminum weld surfaces.
2. Both face- and climb-milling modes are acceptable for preparing aluminum surfaces.
3. High cutting speeds are desirable.
4. Carbide and high-speed steel cutters are satisfactory.

b. <u>Preprototype Device Studies</u>

The preliminary studies provided information on drive motors, cutter types, cutting modes, and cutting speeds that were satisfactory for preparing weld surfaces of aluminum components. Originally, additional Phase I tests were not planned until after the design and fabrication of the prototype device was begun. However, it was considered desirable to fabricate a simple, inexpensive preprototype device to provide further evaluations of mechanical preparation methods before undertaking the design of the more sophisticated prototype device which was fabricated in the Phase II studies.

Two preprototype devices were designed and fabricated. Both were designed to prepare three surfaces (abutting edges and adjacent surfaces) simultaneously. One device was designed to

operate in the face-milling mode--the "face-milling device." The other unit was designed to operate with all three cutters in the climb-milling mode or with two cutters in the climb-milling mode and one cutter in the face-milling mode--the "climb-milling device."

A photograph of the face-milling device is shown in Figure 3. This device consisted of a frame for mounting the drive motors and Teflon-lined guides that extended the length of the device and straddled the plate to hold the device alignment with the plate edge. The device was equipped with three ARO, 2200 Series, 7801-2, 2.42MJ (0.9 hp) motors; one motor was mounted in a vertical position to clean the abutting plate edges, the other two motors were mounted horizontally to clean the surfaces adjacent to the weld. The 2.42MJ (0.9 hp) motors were selected rather than the smaller motors because they provide higher torque and have a heavier motor shaft and bearing. This, in turn, provides smoother cuts, and the motors are less subject to vibration than the smaller motors. Both devices were designed for manual feed, and the motors were held in a fixed position after adjustments for proper depth of cut. Each device weighed about 9.98 kg (22 lb) without the air hoses or chip-collector system.

Both the face- and climb-milling preprototype devices were used to prepare the edges of flat and curved plate simulating a square butt joint configuration. In these tests, the face-milling device proved superior to the climb-milling device because of the greater ease of operation, quality of prepared surface, and deflection of the cutter during cutting and stall conditions. On the basis of these tests, further work with the climb-milling device was terminated.

Tests were continued with the face-milling device to finalize the design concepts for the prototype unit. Tests with the device showed the feasibility of preparing three surfaces simultaneously. These tests also showed the need for several improvements. Cutting operations performed on curved surfaces with

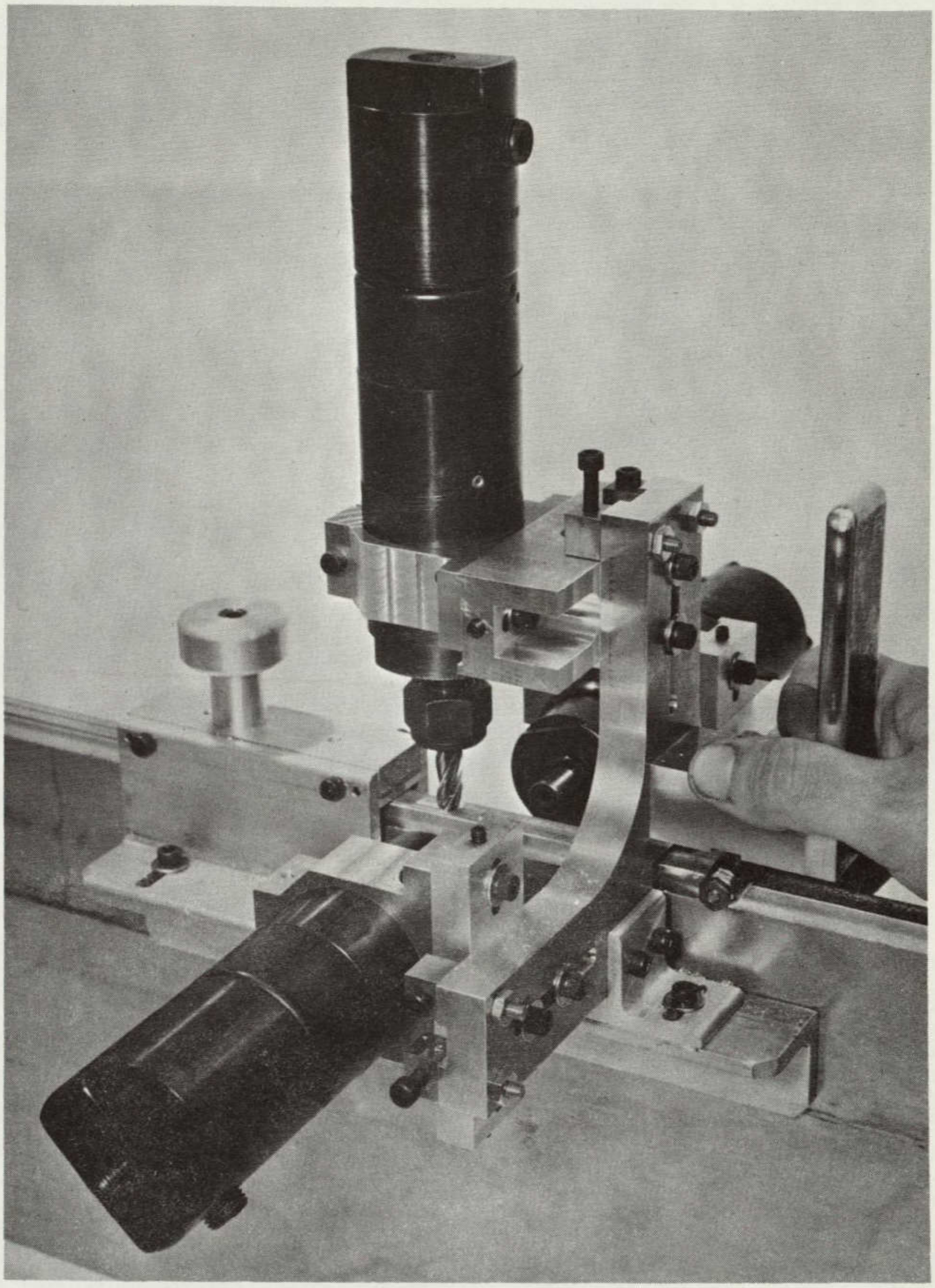

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Fig. 3 - Face-Milling Preprototype Device.

varying curvature of radii, showed that rollers rather than continuous shoes were required to align the device with the plate. Examination of prepared surfaces indicated that a mechanized system was desirable to improve the uniformity of the prepared surface. Cutting on brake-formed parts which did not possess uniform radii of curvature showed the need for a new system to control the depth of cut.

Two improved systems--mechanized drive and controlled depth of cut--were evaluated with the face-milling preprototype device. Mechanized feed was obtained by fabricating an electric motor powered unit which was attached to the cutting unit. Power from the motor was transmitted through a gear train to rollers which were spring loaded to exert pressure on both sides of the plate. Friction between the powered rollers and the plate surfaces was sufficient to pull the cutting unit along the plate edge. A photograph of the drive system is shown in Figure 4.

A number of arrangements were considered for obtaining a positive control over the depth of cut. The major requirement was that the depth of cut must be controlled from the surface of the component. Adaptive controls such as those utilized on tracer lathes were considered, but their use adds to the cost and weight of the unit. It was decided, therefore, that a simple mechanical system should be developed.

The system that was selected to control the depth-of-cut consists of spring loading the motor assembly and providing a small thrust button which extends slightly beyond the cutting face of the cutter and bears on the surface of the plate. A schematic illustration of the basic concepts of the technique is shown in Figure 5. With this arrangement, the cutting surfaces are not in contact with the plate when the cutter assembly is normal to the surface. When the assembly is tilted, however, the trailing edge of the cutter engages the plate. The angle of tilt, extension of the thrust button beyond the cutting edge, and radius of curvature of the surface determine the depth of cut.

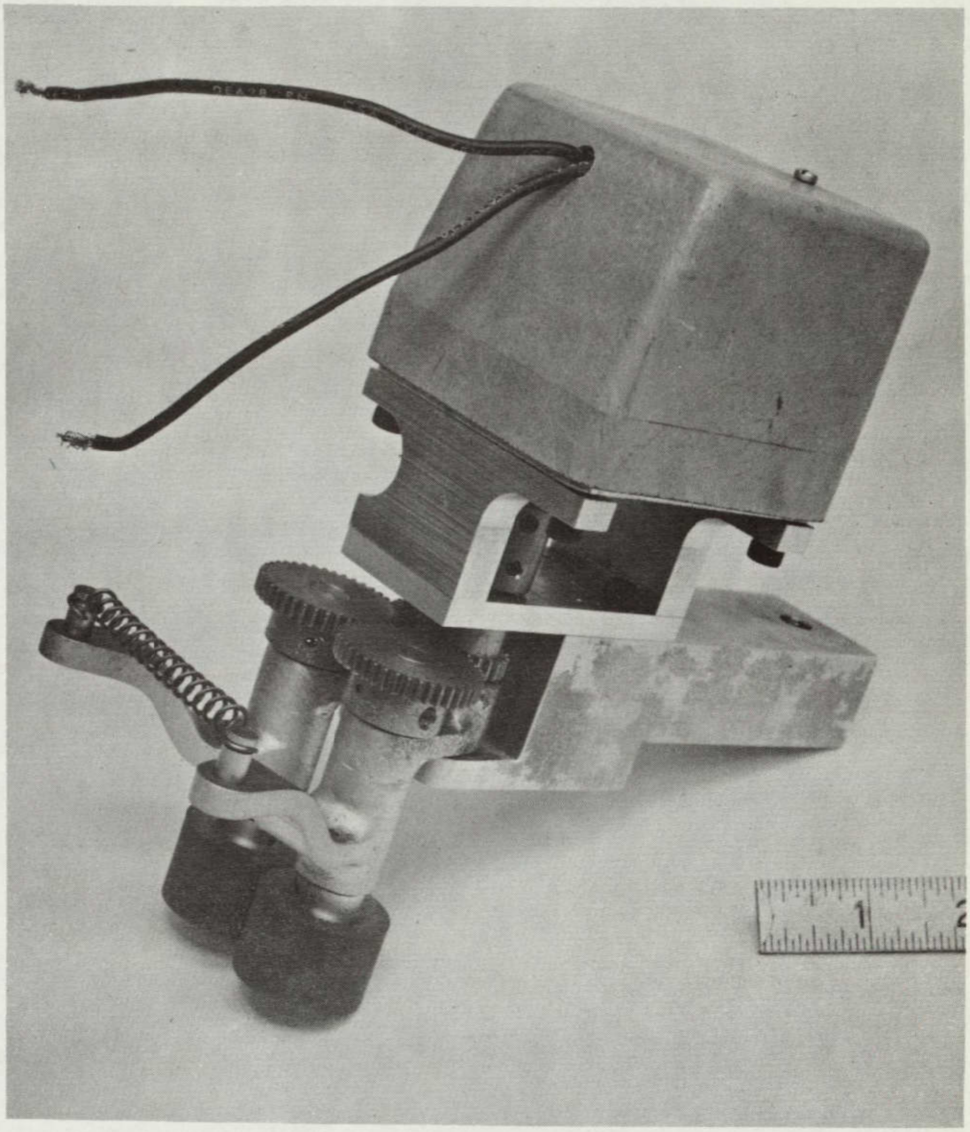

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Fig. 4 - Drive Unit to Provide Mechanized Feed for the Preprototype Device.

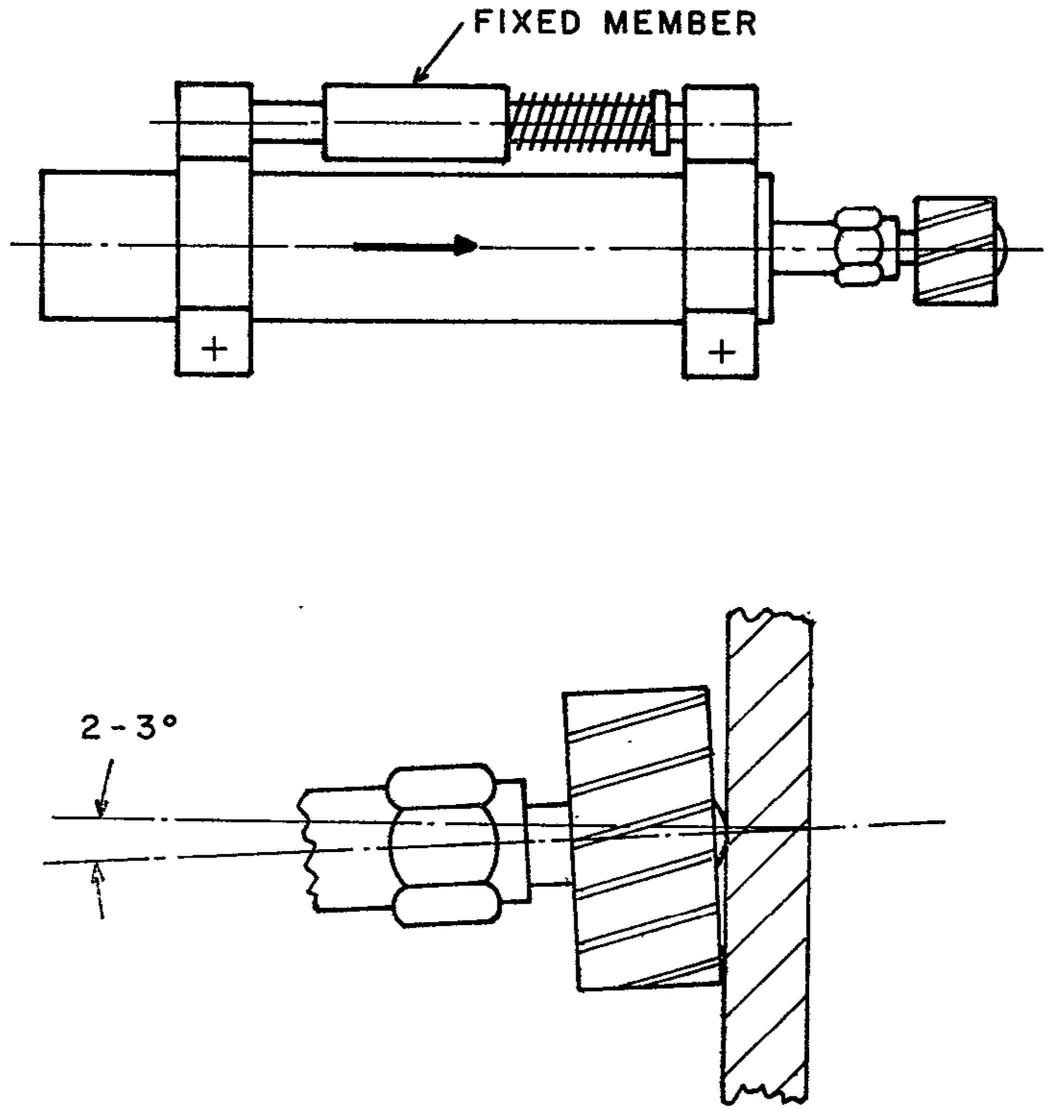
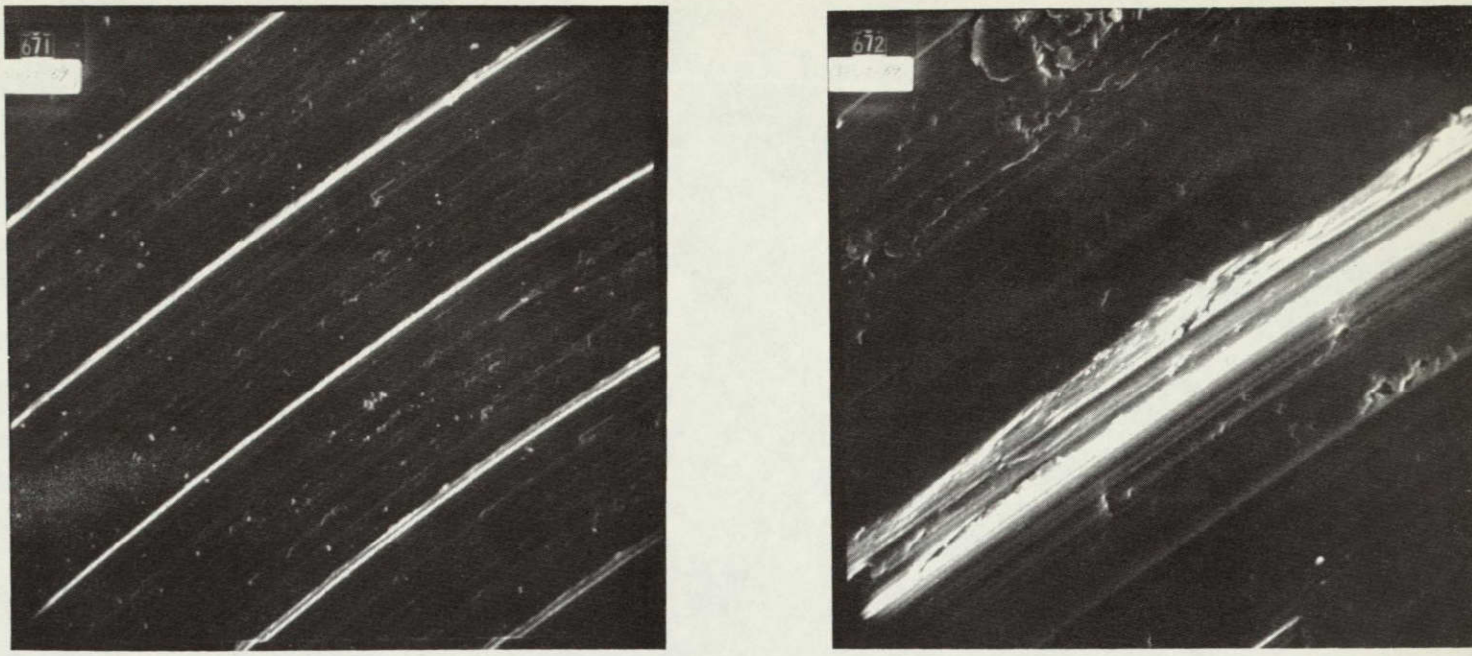



Fig. 5 - Schematic Illustration of System Used for Depth-of-cut Control.

The technique that was developed for controlling the depth of cut proved to be satisfactory for the prototype device. Initially, the spring-loaded cutter assembly was mounted on the face-milling device. The quality of the surface prepared with the spring-loaded device was excellent, but fine adjustments on the tilt angle were not possible. Subsequently, the assembly was mounted on the spindle of a milling-machine to provide more accurate control over the tilt angle.

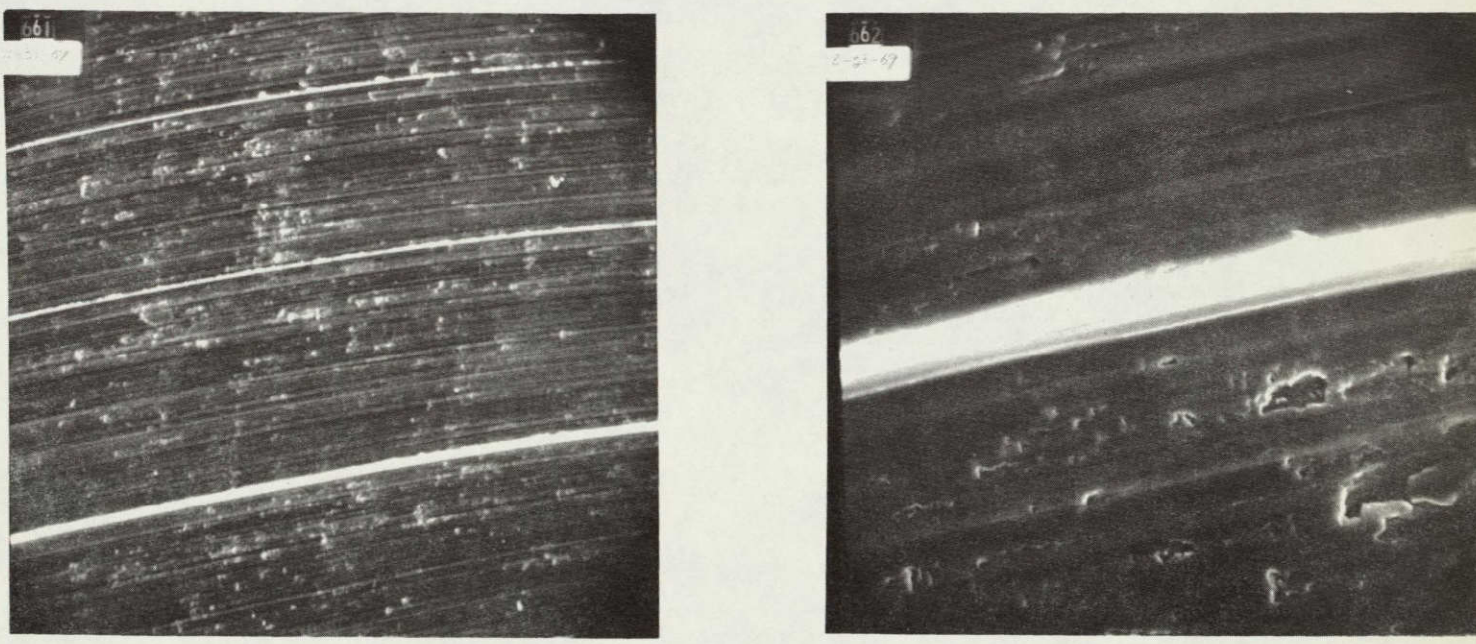
Two limitations were found with the depth-of-cut control system. One is that the tilt angle must be carefully controlled. To achieve this control, the cutting unit must be precisely and rigidly aligned with the edges of the plate. The second limitation is that the surface of the cut conforms to the contour of the trailing edge of the cutter and is slightly concave. Thus, the depth of cut varies and is greatest along the centerline of the cutter. If the center of the cutter is located a significant distance below the edge of the plate, maximum thinning of the material may be located in an area that will subsequently form the weld heat-affected zone. Such a condition is undesirable; therefore, care must be taken to align the cutter so that the centerline is located in an area that will be within the fusion zone of the weld bead and thinning will be compensated for by the weld reinforcement.

Surfaces that were prepared with the controlled depth-of-cut assembly were evaluated with the scanning electron microscope and with fusion spot-weld tests. Two cutters with different diameters, 31.8 and 38.1 mm (1 1/4 and 1 1/2 in.), were used to prepare the surfaces. Micrographs obtained with the SEM are shown in Figures 6 and 7. These surfaces are similar to the dry machined surfaces observed in the previous study.[1] A typical fractured fusion spot weld is shown in Figure 8. All spot welds contained fine scattered porosity but were free from oxide inclusions and lack of fusion. Defect potential ratings varied from 1 to 5.



SEM 671 100X (a) SEM 672 1000X (b)

Fig. 6 - Scanning Electron Micrographs of Surface Prepared with 31.8 mm (1 1/4 in.) Diameter Cutter.



SEM 661 100X (a) SEM 662 1000X (b)

Fig. 7 - Scanning Electron Micrographs of Surface Prepared with 38.1 mm (1 1/2 in.) Diameter Cutter.

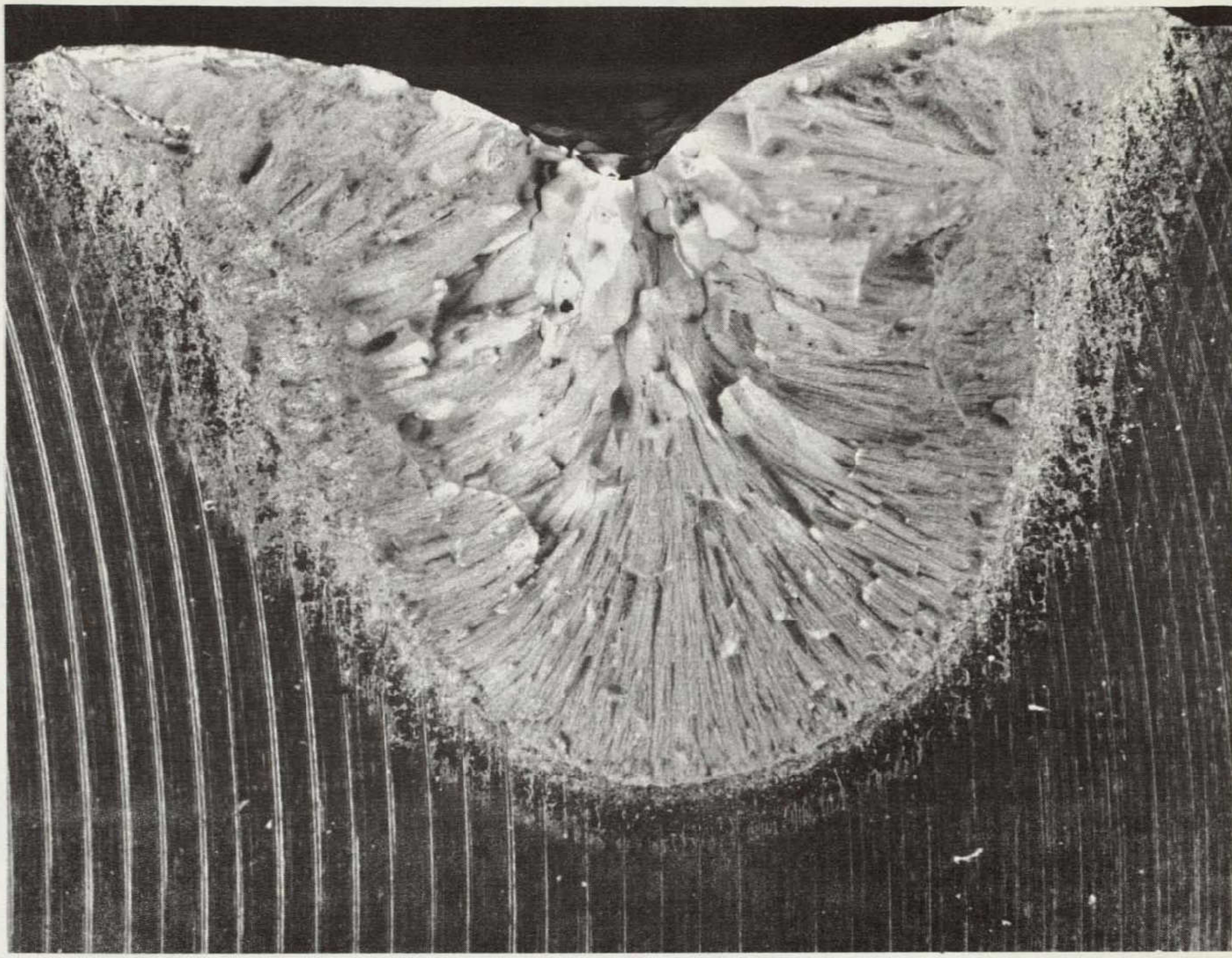


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Fig. 8 - Fusion Spot-Weld Test Sample from Dry Machined Specimen.

The information obtained in the final studies on mechanical cleaning methods showed the feasibility of fabricating a mechanical cleaning device to prepare three weld surfaces simultaneously with close control over depth-of-cut and excellent surface quality. On the basis of these studies, work was initiated on the design and fabrication of the prototype device for Phase II.

## 2. Electric Discharge Cleaning Methods

Electric discharge methods were evaluated as supplementary cleaning methods should the machined surfaces be accidentally contaminated before welding. Electrical discharge cleaning has been recognized for many years and is credited with the success achieved in welding aluminum alloys in the alternating current mode. Cleaning occurs during that portion of the cycle when the workpiece is at negative potential with respect to the torch electrode (reverse polarity). In this mode, cathode spots tend to form on surface oxides, which usually have superior emitting powers than the pure metal. The localized charge present at the cathode spot removes the oxide either by ion flow, as suggested by Pattee et al.,[2] or by superheating the metal substrate below the oxide until it is exploded from the surface. Both mechanisms explain the cleaning action that is possible with this method.

The feasibility of electric discharge cleaning was explored in previous NASA sponsored programs,[1,2] and the results were promising but not entirely conclusive. In previous IITRI work, it was found that adsorbed water and trichlorethylene could be substantially desorbed by arcing and high-frequency sparking treatments, but oxide removal was only partially complete and the weld defect potential was not consistently low. Pattee et al.[2] reported that cathodic cleaning with a plasma arc was as effective as abrasive cleaning on the basis of surface resistivity measurements and welding tests. However, the ultimate objective of this program was to develop surface preparation techniques superior to abrasive methods.

a. Preliminary Studies

Preliminary studies with electric discharge cleaning were performed to evaluate various cleaning modes; all modes involved discharge with low energy input. Low energy was used because the effectiveness of the reverse-polarity welding arc as a surface cleaning device is limited if extensive melting occurs (as it does in normal welding applications). Water of hydration, adsorbed hydrocarbons, oxide fragments, etc., dissociate in the arc atmosphere or molten metal and form entrapped defects (such as porosity and inclusions). Molten aluminum is especially receptive to atomic hydrogen and can also easily entrap oxides.

Low energy arc and spark discharges were evaluated to determine if an optimum range of conditions (energy, frequency, scanning speed, atmosphere, etc.), which would lead to the nearly complete removal of oxide film and adsorbed contaminants without surface melting, could be developed. Investigations by Corey[3] on the cathodic etching of metal surfaces has demonstrated that a 4 amp direct-current reverse-polarity argon arc with superimposed radiofrequency excitation can be used to etch aluminum, zirconium, uranium, and copper. Optimum surface smoothness is often achieved at pressures somewhat under one atmosphere; however, even at atmospheric pressure substantial surface etching occurs. Corey did not characterize the cleanliness of the surface, nor did he attempt to investigate arc or spark variables. Interestingly, he did find that the radiofrequency spark alone produced fine etching. Corey's findings are in general accord with those of the previous NASA study.[1]

Three electrical discharge conditions were investigated:

1. Pulsed direct-current reverse-polarity
2. Radiofrequency
3. Steady-state direct-current reverse-polarity

Test specimens for electrical discharge cleaning evaluations were first dry machined to produce a surface with low defect potential and then deliberately contaminated, retaining some

specimens in the as-machined condition for experimental control purposes. The following surface conditions were evaluated:

1. As-machined and carefully stored
2. Alconox degreased
3. Chemically cleaned (1 min in 5 w/o NAOH solution at 180°-190° F, dipped in demineralized water, 15 sec dip with agitation in 50 v/o $HNO_3$ to remove smut, followed by a 1 min rinse in demineralized water)
4. Trichlorethylene degreased.

Cleaning was performed with conventional gas tungsten-arc welding equipment mounted on a side beam carriage and equipped with an oscillator to provide longitudinal and transverse travel over the specimen surfaces. A photograph of a cleaning operation with direct-current reverse-polarity discharge is shown in Figure 9.

b. Pulsed Direct-Current Reverse-Polarity Discharge Cleaning

Cleaning with pulsed direct-current reverse-polarity proved to be the best electric discharge technique that was studied in the program, but cleaning was unacceptable. Initial tests were made with a peak current time of 0.15 sec and a base current time of 0.35 sec to establish parameters that would provide stable operations. These initial tests were performed without arc oscillation as the arc traversed the test specimen.

Effective cleaning was obtained with peak current values of 50 and 25 amp and travel speeds of 508 and 254 mm/min (20 and 10 ipm), respectively. At these current values the arc was stable and appeared to be concentrated ahead of the electrode at the forward edge of the cleaned area. Many cathode spots were observed to form and rapidly break down as the arc traversed the surface. The effective width of cleaning was approximately 12.7 mm (1/2 in.). Oscillation was required to clean a 25.4 mm (1 in.) wide surface.

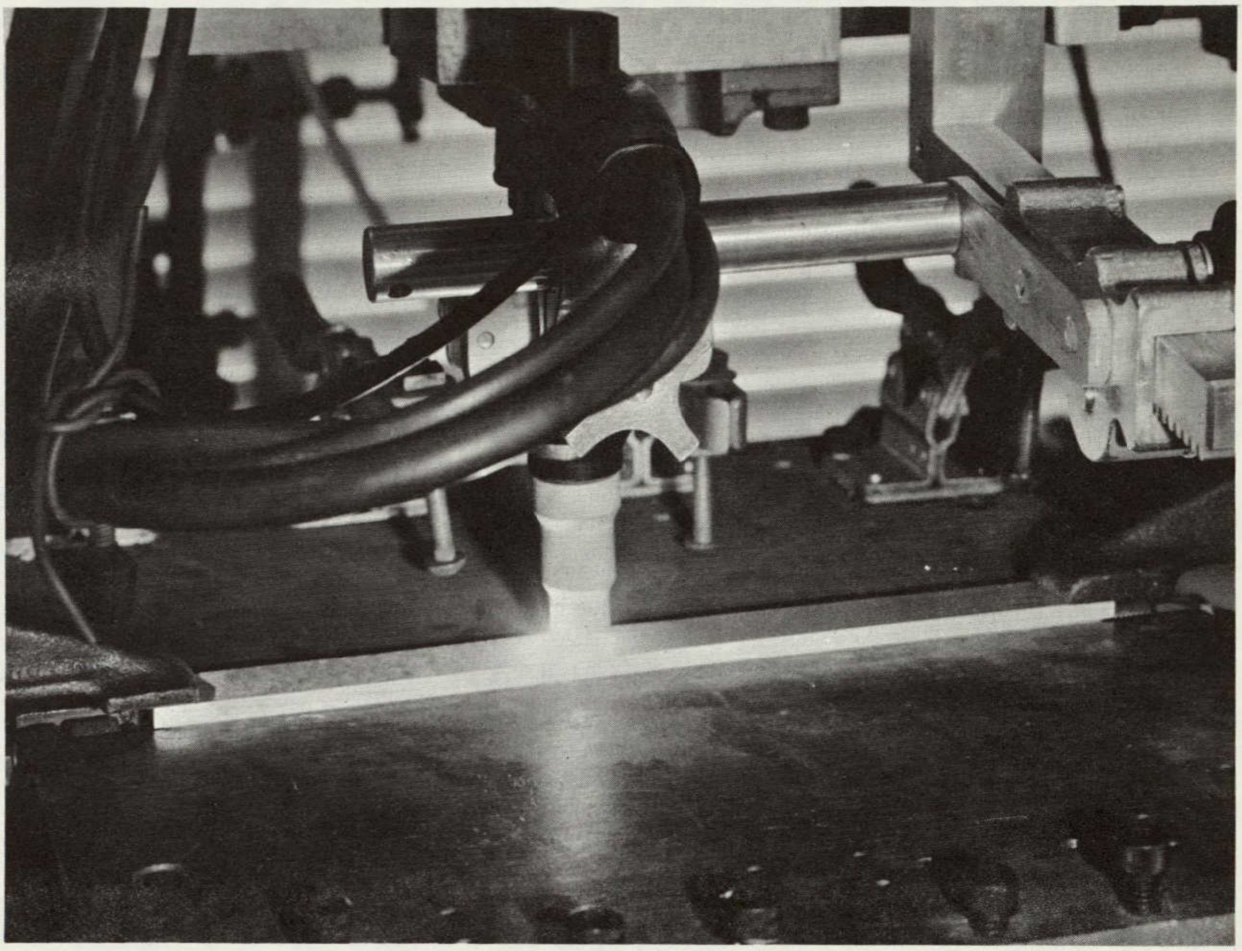

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Fig. 9 - Electric Discharge Cleaning with Direct-Current Reverse-Polarity Discharge.

Preliminary tests were carried out to determine a favorable range of cleaning parameters for oscillating the electrode. Variations in arc current pulsation, electrode gap, shielding gas flow, scanning rate, and travel speed were investigated. The following conditions were established as a base for the pulsed direct-current reverse-polarity experiments with electrode oscillation:

Electrode: 3.97 mm (5/32 in.) diameter thoriated tungsten

Electrode gap: 3 mm (0.117 in.)

Electrode extension: 1.4 mm (0.055 in.)

Electrode cup size: 12.7 mm diameter (0.5 in.)

Argon gas flow: 1.3 $m^3$/hr (46 cfh)

Peak current, frequency of pulsation, oscillation rate, and travel speed were varied. The close interrelationship of the variables severely limited the range of conditions that could be studied. For example, Figure 10 shows a condition where arc cleaning is satisfactory but the oscillation rate is too slow for the traverse speed or vice versa, and surface "sooting" prevents adequate cleaning.

As the travel speed increases, the number of oscillations must be increased to achieve good cleaning. With increasing current, oscillation rates may be reduced with a given travel speed. A counteracting influence is the onset of material surface and edge melting which occurs with increasing current, increasing peak current time, decreasing travel speed, and decreasing oscillation rate. Current levels also were limited by melting of the tungsten electrode. Because of these various interactions, cleaning was achieved only over a relatively limited range. A heat input of 4,000 to 5,000 joules/in.$^2$ is required for surface cleaning. Values above these tend to cause surface melting.

Cleaning the 6.35 mm (1/4 in.) thick edges of the specimens proved to be very difficult, as the arc stabilized on one edge would not detach easily. After many tests it was concluded that all edges would have to be cleaned with a peak current of 35 amp and

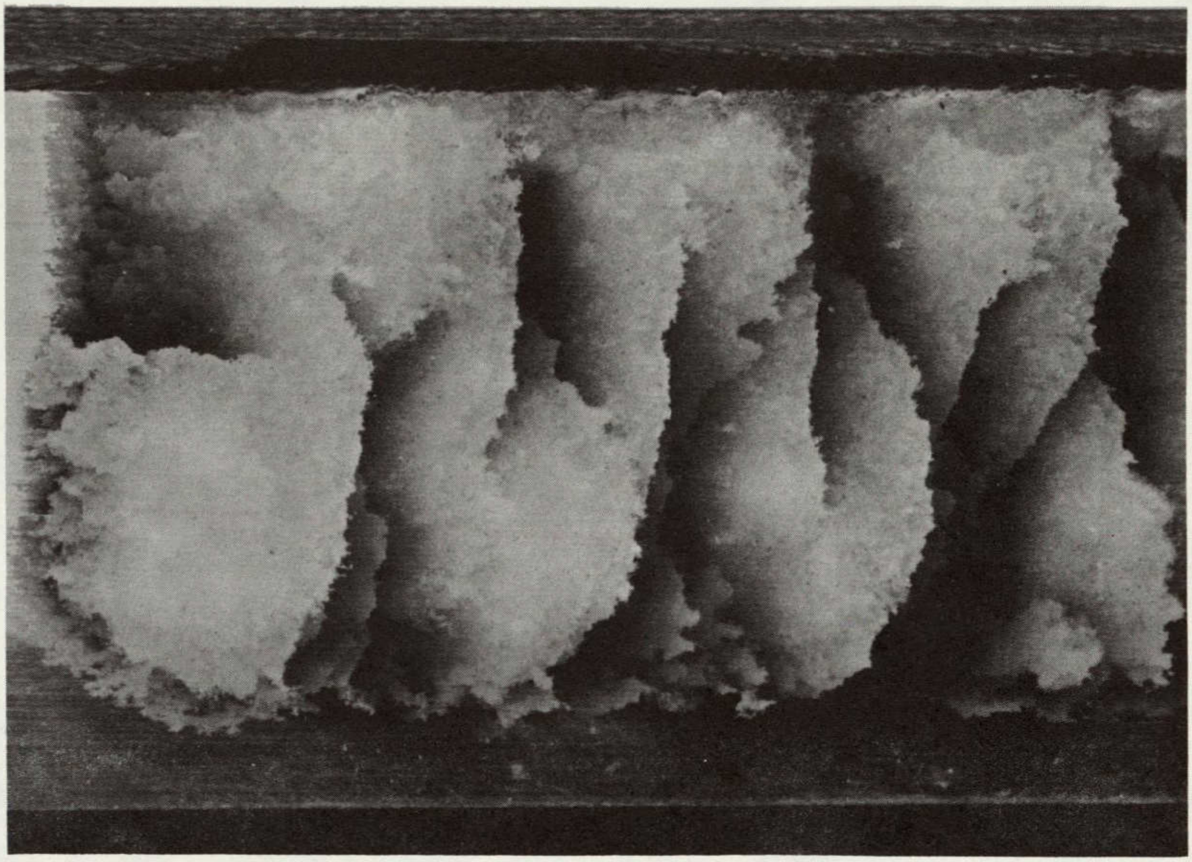

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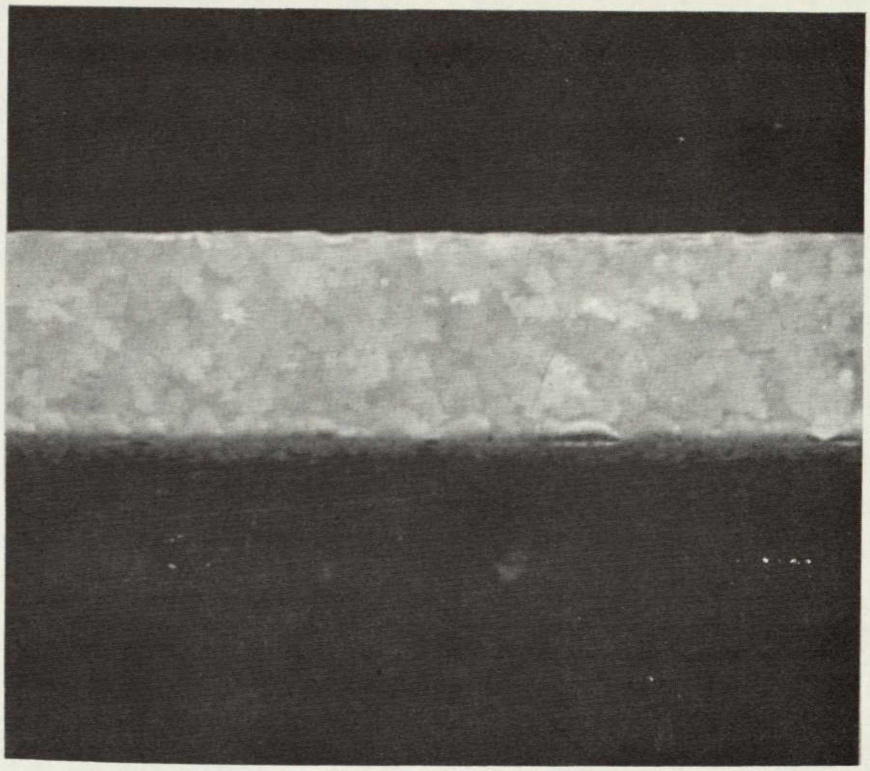
Fig. 10 - Sooted Surface as a Result of Improper Oscillation Rate or Traverse Speed on Specimen Cleaned with Pulsed Direct-Current Reverse-Polarity Discharge.

with superimposed radiofrequency discharge to achieve arc stability. A peak current time of 0.15 sec and base current of 12.5 amp at 0.35 sec with a travel speed of 254 mm/min (10 ipm) without oscillation provided the best results for cleaning edges of the plate. Figure 11a shows the edge cleaning achieved at the optimum settings. Slight edge melting was unavoidable.

A series of test specimens were prepared using the parameters established for cathodic cleaning. Two specimens were prepared at each setting to enable evaluation of the cleaning technique using the fusion spot-weld test. Chemically cleaned samples were selected for analysis, as previous work had established that this was the worst condition encountered among the normal "cleaning" methods. Figure 11b is typical of the surface cleaning achieved. Complete surface coverage is obtained with only occasional surface melting; the marble-like sputtered surface finish is very prominent.

The specimens produced for spot-weld tests were mainly satisfactory with two notable exceptions. Figure 12 shows a sample produced under conditions similar to those of the specimen in Figure 11b but a badly pitted surface resulted. The arc characteristic changed entirely to produce myriads of bright intense cathode spot areas causing excessive surface eruption. No systematic study was made of this phenomenon. However, if cathodic cleaning is ever to be used, further work to determine the reasons for variable cleaning actions with similar settings is essential. Difficulties were also experienced when the nature of the surface contamination changed. In an attempt to achieve comparative results, the same cleaning parameters were used for the differently treated surfaces. It was obvious that the optimum conditions for cleaning chemically cleaned surfaces were not as successful for the other surfaces.

Visual examination of the specimen surfaces revealed variations in the cleaning action of the arc. Surface melting varied from substantial amounts to very small spots of incipient surface



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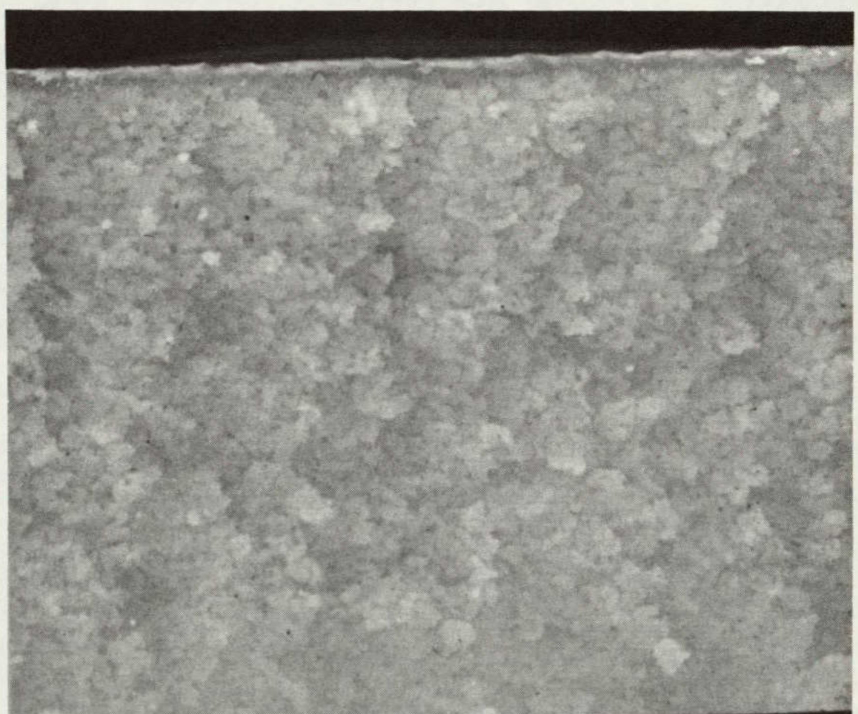
(a) Edge



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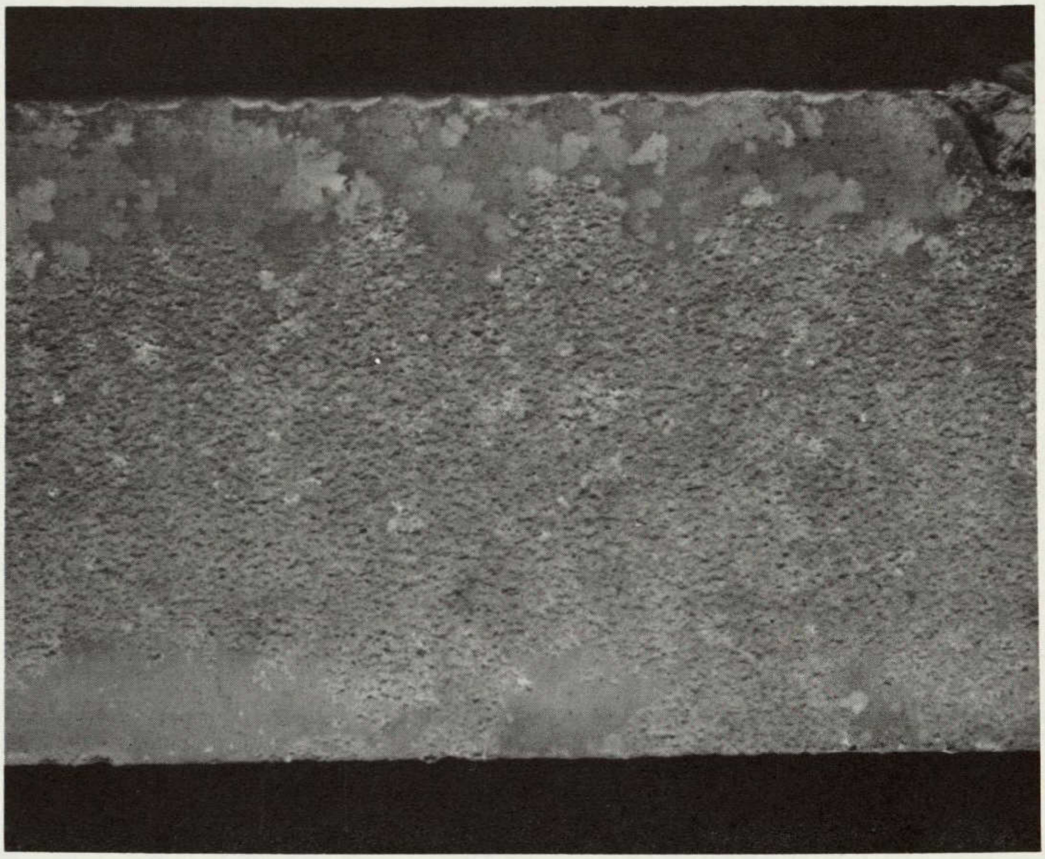
(b) Surface

Fig. 11 - Views of Specimen Cleaned with Pulsed Direct-Current Reverse-Polarity Discharge.



Neg. No. 35730 3.5X

Fig. 12 - Badly Pitted Surface of Specimen Cleaned with Pulsed Direct-Current Reverse-Polarity Discharge.

melting as typified in Figure 11b. Most specimens showed surface cracking of an intergranular nature, although this varied according to the parameters used. This examination showed that even the specimens that were apparently clean had many defects and could not be generally recommended.

Evaluation of the effect of cathodic cleaning parameters on reducing defect potential was based on the horizontal fusion spot-weld test. According to the previously established relative scale of defect potential, all of the samples that were cathodically cleaned gave poor results. Figures 13 and 14 are examples of the defects noted. Gross porosity in Figure 13 shows a high defect potential, and the oxide fold shown in Figure 14 is a potential source of lack-of-fusion defects in weldments.

Samples representing the original contaminated surface conditions that were subjected to electric discharge cleaning also were subjected to the fusion spot-weld test. In practically all cases, these samples had lower defect potential than the specimens cleaned by electrical discharge. As expected, the as-machined specimens were better on the basis of defect potential.

c. <u>Radiofrequency Discharge Cleaning</u>

Initial tests with radiofrequency discharge were performed by heating a spot on the specimen. A conventional radiofrequency power source of the type used to start welding arcs was employed. The high frequency current was supplied to a 3.97 mm (5/32 in.) diameter electrode, and argon shielding gas was used. The spot cleaning tests were performed with variations in electrode-to-work distance. Good cleaning action was observed and varied inversely with electrode spacing.

After the initial spot cleaning studies, the electrode was traversed over the specimen surface. When the electrode was traversed, the results generally were unsatisfactory; only intermittent cleaning was observed. One reason for the lack of success in cleaning with radiofrequency discharge was that the minimum

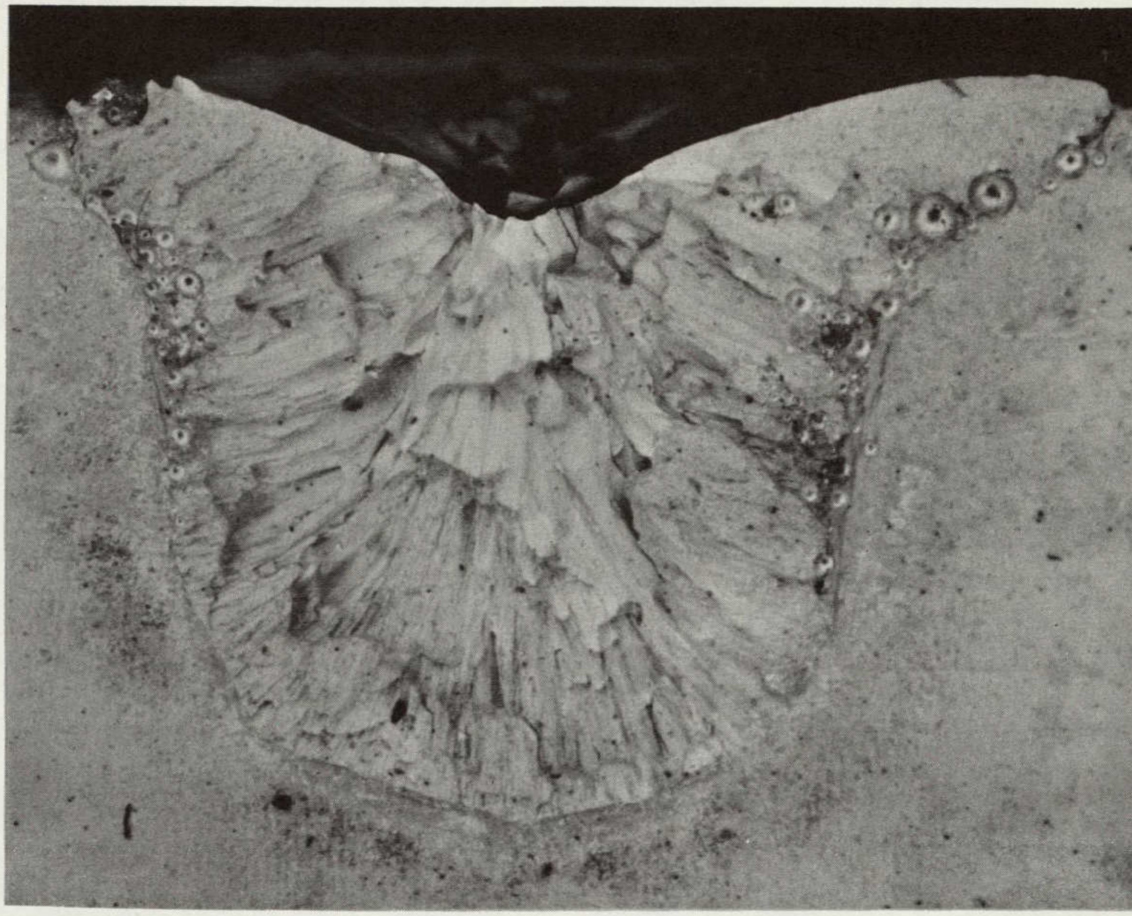


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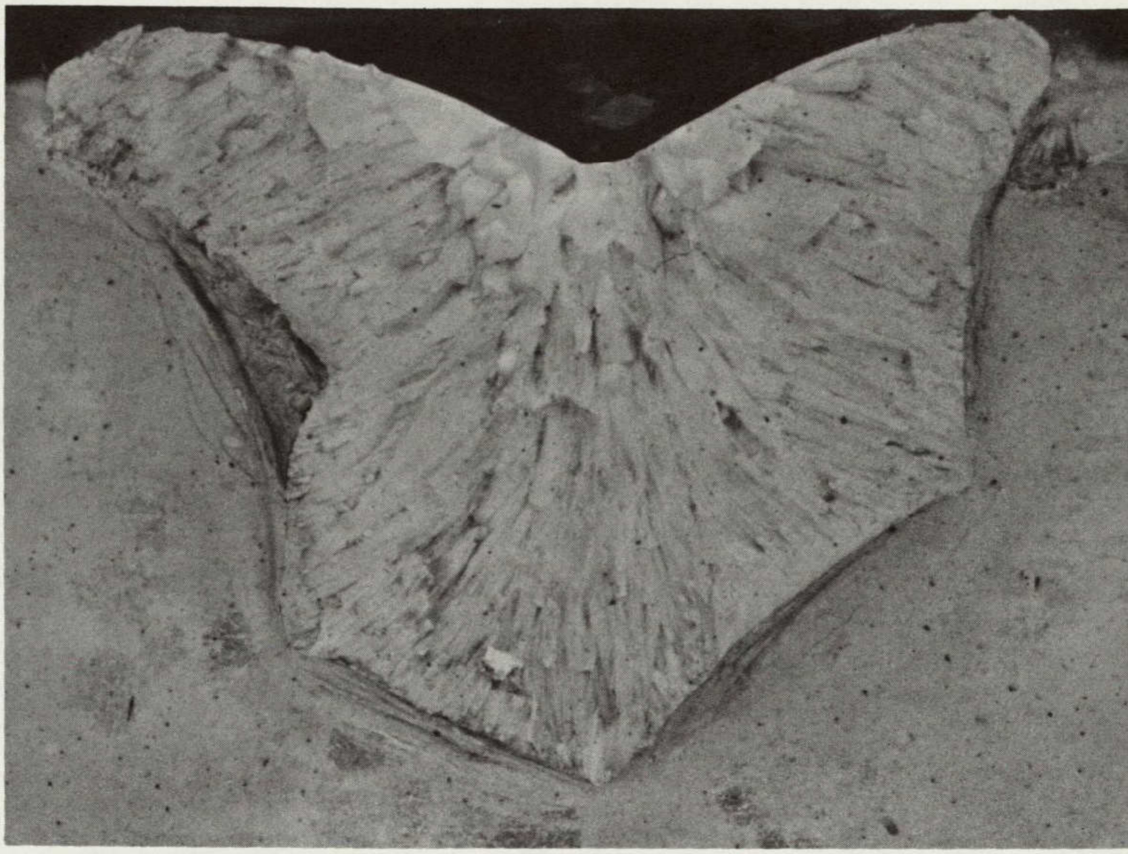
Fig. 13 - Fusion Spot-Weld Test of Cathodically Cleaned Sample Showing Gross Porosity.



Neg. No. 35733 17X

Fig. 14 - Fusion Spot-Weld Test of Cathodically Cleaned Sample Showing Heavy Oxide Folds.

travel speed, 30 mm/min (1.2 ipm), which could be achieved with the equipment was too high to allow adequate cleaning.

It was concluded from these tests that radiofrequency cleaning is inadequate under the conditions that were employed. It may be possible that improved cleaning could be achieved with a different power source and electrode system. However, work with high-frequency discharge cleaning was terminated.

d. Steady-State Direct-Current Reverse-Polarity Discharge Cleaning

Electrical discharge cleaning with conventional direct-current reverse-polarity discharge was performed to establish a range of useful parameters for cathodic cleaning. For these studies the following parameters were investigated:

Arc-current: 25-75 amps

Electrode-to-work distance: 3.18-6.35 mm (1/8-1/4 in.)

Argon gas flow rates: 0.6-1.5 $m^3$/hr (21-53 cfh)

Electrode extension: 1.59 mm (1/16 in.)

Nozzle diameter: 9.5-15.9 mm (3/8-5/8 in.)

Electrode diameter: 3.97 mm (5/32 in.)

Travel speed: 508 mm/min (20 ipm)

Initial tests were performed with an arc current of 25 amps. At this current level, the arc was diffuse and oscillated rapidly over the surface of the specimens. Occasionally, the arc was stabilized by cathode spots on the surface, followed by rapid movement. This action resulted in a generally sooty deposit following the passage of the arc. Good cleaning was not achieved.

When the welding current was increased to 50 amps, arc stability increased but cleaning action was still poor. When the current was increased to 75 amps, improved cleaning action was observed; however, the arc traversed the surface by direct steps--stopping at apparently stable cathode spots where the aluminum melted, then rapidly traversing the surface until another stable

spot was formed. The resultant surface appeared clean, but uneven, resembling a somewhat marbled finish with variable reflecting surfaces. Although this current level provided a relatively clean surface, electrode melting was a problem. Work with this technique also was terminated.

In summary, all efforts to reduce the defect potential of aluminum surfaces by electric discharge methods were unsatisfactory. Even when good cleaning action appeared to occur with pulsed direct-current reverse-polarity discharge, the defect potential was not reduced. Apparently, cleaning was not adequate or the surfaces rapidly adsorbed contaminants after cleaning was completed.

### C. Conclusions

It was demonstrated that mechanical cleaning operations are practical for the preparation of aluminum weld surfaces with low defect potentials. Lightweight air motors provide sufficient power to machine surfaces to meet the requirements of the program. Both the face- and climb-milling modes are satisfactory, but face-milling provides greater ease of operation and better control over dimensional tolerances. A mechanized drive system proved preferable to manual movement, and three surfaces can be prepared simultaneously. A system was developed to control depth of cut.

All electrical discharge cleaning methods were unsatisfactory, on the basis of defect potential, under the conditions investigated in the program.

## III. PHASE II - DESIGN AND FABRICATION OF PROTOTYPE DEVICE

Based on the Phase I studies, dry machining of weld surfaces was selected as the most practical method for preparing aluminum weld surfaces to achieve a low defect potential. In the Phase II studies, a prototype device was designed and fabricated. A decision was made to design the unit to prepare square butt joint

configurations to demonstrate the feasibility of the technique and systems that were selected. The same unit can be used on "U" joint configurations, but incorporation of adjustments in the device to prepare single and double Vee configurations were not made for fear that they would jeopardize satisfactory performance of the prototype device. The prototype device is described in the following.

## A. Design and Construction Features

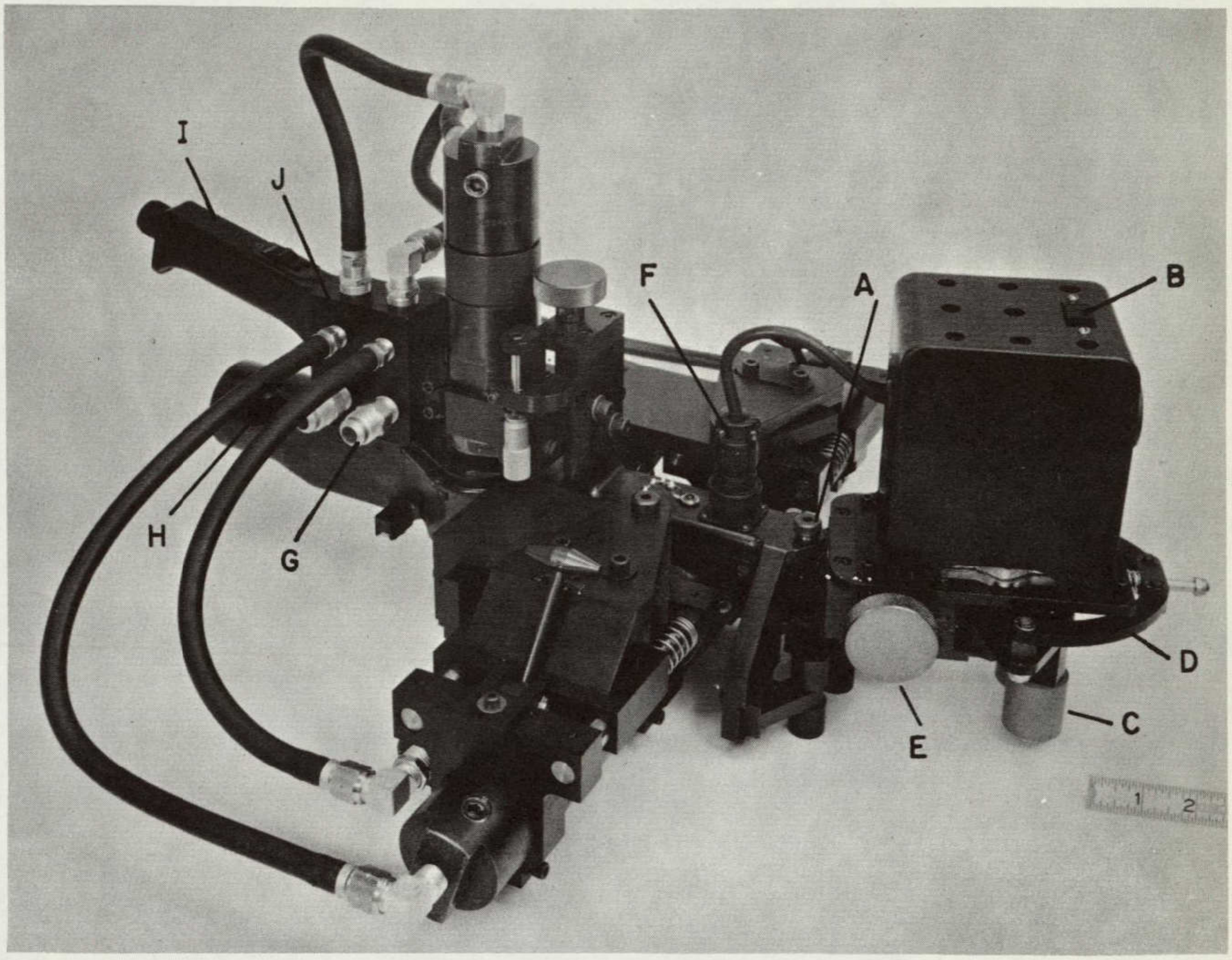
Concepts for the design of the prototype device were developed in the Phase I studies. The basic concept was to develop a device which could be mounted on the edge of the aluminum plate or component and which would traverse the edge of the component. Other design concepts were: (1) the use of air motors to drive the milling cutters, (2) the use of a mechanically driven unit to provide uniform cutting speeds, (3) the use of the face-milling machining mode, and (4) the simultaneous preparation of three surfaces (the abutting edges and two adjacent surfaces).

The prototype device is shown in Figure 15. A drive unit and a cutting unit are joined with a clevis (A) to allow the device to traverse the edges of both straight and curved aluminum components.

## B. Drive Unit

The drive unit is attached to the forward end of the cutting unit and is powered by an electric drive motor. An electric switch (B) activates the drive motor and is mounted on the forward upper surface of the unit.

Power from the drive motor is transmitted through a gear train to two polyurethane-coated drive rollers (C) which are forced into firm contact with the surfaces of the component adjacent to the weld edge to provide a positive friction drive. A spring-loaded clam-shell device (D) is utilized to provide firm contact. The spring-loaded clam-shell device is visible in Figure 16, which shows the bottom of the drive unit. Adjustment of the drive rolls is

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Cutting Unit Drive Unit

Fig. 15 - Prototype for Weld-Surface Preparation of Aluminum Components.

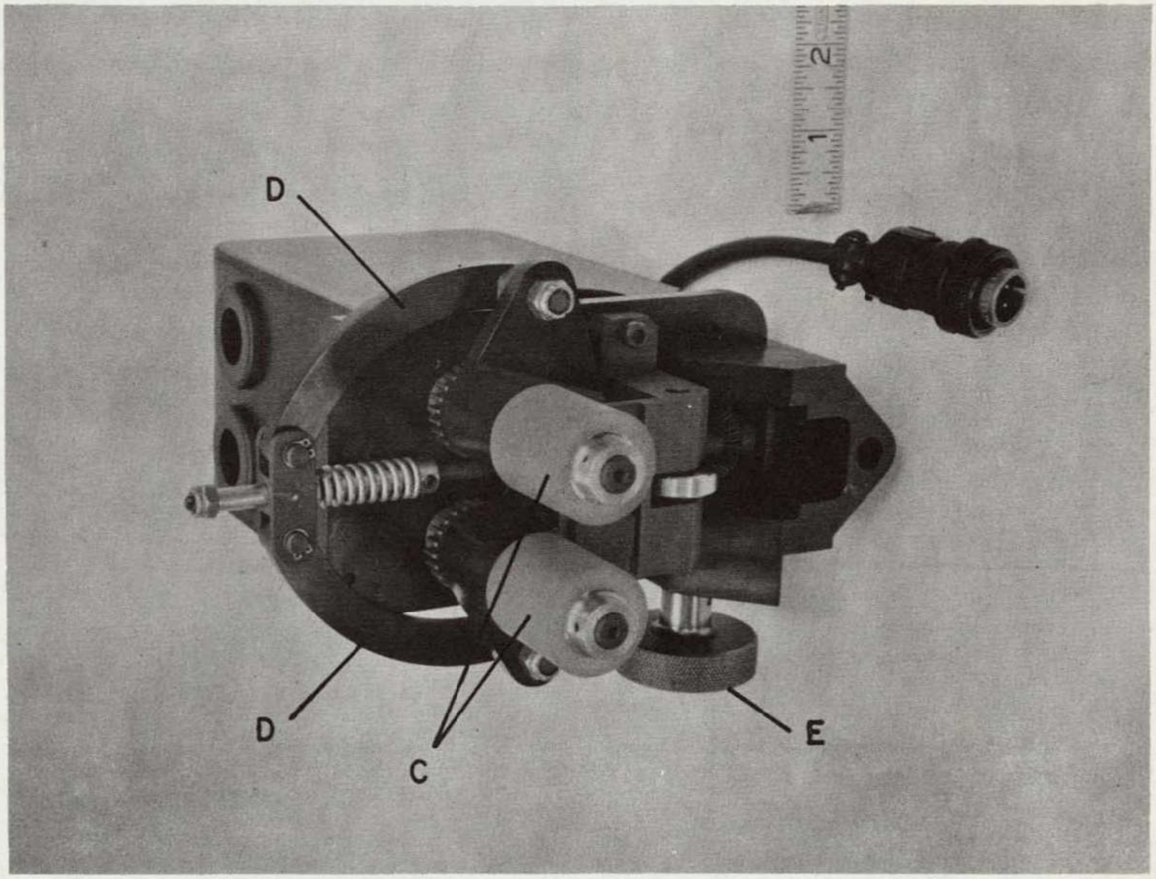


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Fig. 16 - View of the Bottom of the Drive Unit.

accomplished by manually rotating a knob (E) which is located at the lower left corner of the drive unit (Figure 15). This adjustment will accommodate plates ranging in thickness from 2.54 mm (0.1 in.) to 25.4 mm (1.0 in.).

Electric power for the drive unit is supplied through a plug (F) located on the forward end of the cutting unit (Figure 15). A cap is provided for the plug and is utilized when the cutting unit is operated independently of the drive unit. The drive unit is designed to propel the device at a linear speed of approximately 914 mm/min (36 ipm). This speed was selected on the basis of the Phase I studies.

## C. Cutting Unit

The cutting unit consists of a rigid body to which are attached the milling drive motors, depth-of-cut control systems, alignment rollers, and edge-breaking tools. As seen in Figure 15, the body of the cutting unit is fabricated from a rectangular steel tube (G) with welded attachments for use in mounting the system. A rectangular steel tube was selected to achieve rigidity and to provide air passages for a vacuum chip-removal system. The rear end of the body is welded to a cylinder (H) to provide means for attaching a shop-type vacuum cleaner for chip removal and collection. The handle (I) is mechanically fastened to the body and can be removed in operations where it is desirable to mount the cutting unit in a stationary position and move the component that is being prepared. Incorporated into the handle is a gas manifold system (J) to supply air to the milling motors and to collect the exhaust air from the motors. The switch on the handle activates a gas solenoid; the solenoid is located at the air supply station which supplies air to the milling drive motors.

A photograph of the front of the cutting unit is shown in Figure 17, the rectangular shape of the body, the clevis (A) for attaching the drive unit, and the attachment (K) for the forward alignment rolls (L) are readily visible. All welded attach-

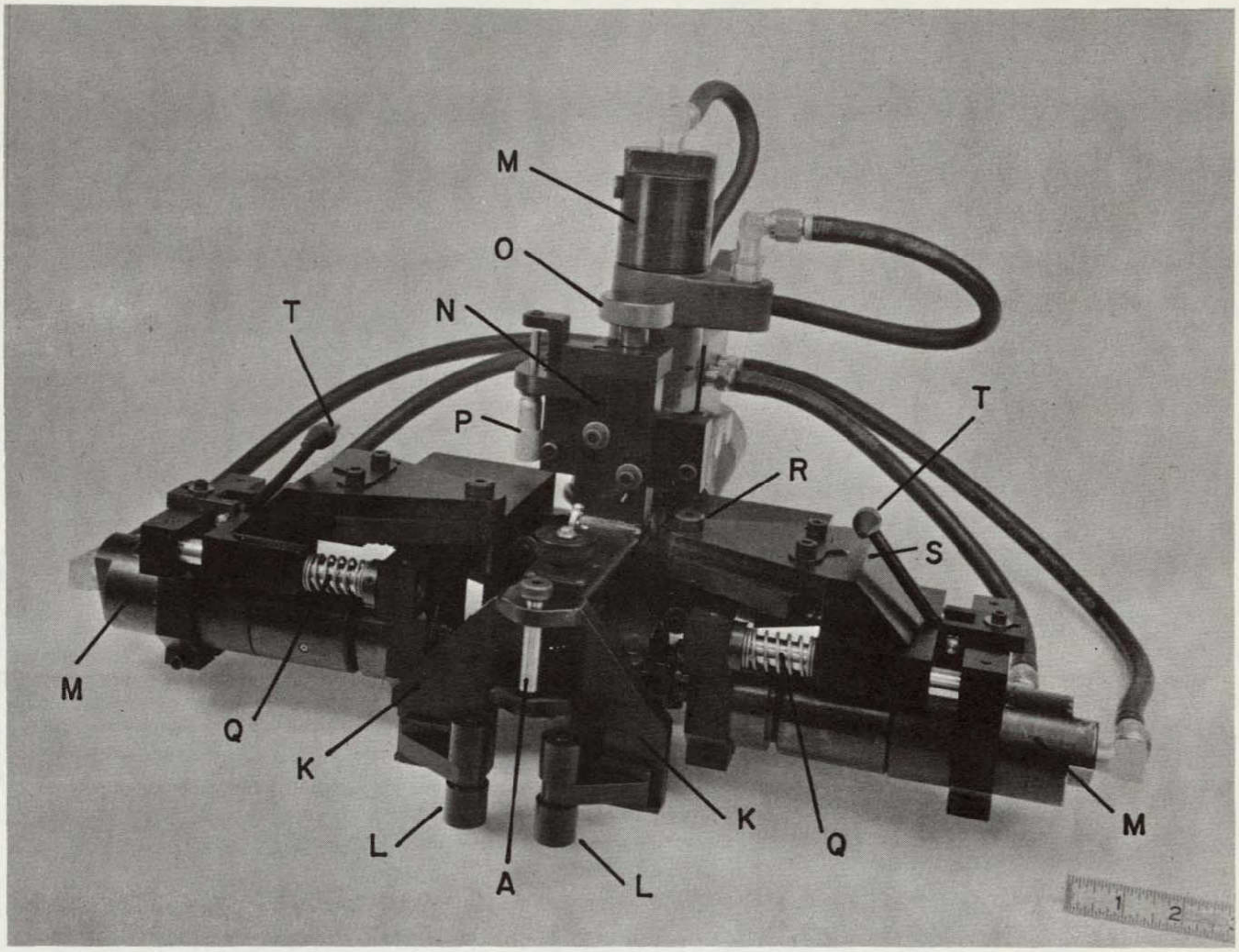


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Fig. 17 - Front View of Cutting Unit.

ments were heavy to insure rigidity, as illustrated by the attachments for the forward alignment rollers.

Three milling motors (M) are mounted on the body; one in the vertical position to prepare abutting edges, and two in the horizontal position to prepare the surfaces immediately adjacent to the edge. The vertical motor is attached to a slide (N) to provide for depth-of-cut adjustments. Immediately in front of the motor (Figure 17) is a knob (O) for manually adjusting the vertical location of the motor and slightly to the left is a micrometer (P) which allows the measurement of the depth-of-cut adjustment. The vertical unit is held stationary during surface preparations.

The horizontal cutting units are fitted with depth-of-cut control systems, which adapt to the surfaces that are being prepared. A simple mechanical system was developed to provide this control. Control is achieved by spring loading (Q) the horizontal milling motor assemblies and providing a small thrust button which extends beyond the cutting surface of the milling cutter and bears on the surface of the plate. With this arrangement the cutting surfaces are not in contact with the surface to be prepared when the motor is normal to the surface. When the assembly is tilted, the trailing edge of the cutter engages the plate. The angle of tilt, the extension of the thrust button beyond the cutting surfaces, and the radius of curvature of the component determine the depth of cut.

Once the proper settings are made, the depth of cut is controlled directly by the thrust button which rides on the surface to be prepared (see Figure 5). Each milling motor is equipped with a multiflute helix-shell end mill, 31.8 mm (1 1/4 in.) diameter. The vertical motor and the horizontal motor on the right are equipped with right-hand cutters. The other horizontal motor is equipped with a left-hand cutter. The spring-loaded horizontal motor mounts (R) are pivoted so that the cutter can be tilted to control

the depth of cut. Graduations (S) are machined on the mount for measuring the degree of tilt and to assist in adjusting the depth of cut.

The depth-of-cut control system used on the horizontal cutters results in a slightly concave machined surface on the component. This feature is desirable for a smooth transition from the original surface to the machined surface. However, care must be taken to insure that the area which is machined to the greatest depth lies within the fusion zone of the weld to be made, otherwise maximum thinning can occur in an area that will be located within the heat-affected zone after the components are welded.

Vertical slides, which are not visible in the photos, are incorporated into the horizontal motor mounts to control the location where maximum depth of cut occurs. The area of maximum depth of cut corresponds to the center of the thrust button. With the vertical adjustment, the center of the thrust button can be located at various distances below the edge of the component. The width of the machined surfaces adjacent to the edge is determined by the position of the thrust button and by the depth of cut. As the depth of cut is increased, the width also increases. As the thrust button is moved further away from the edge, the width of the prepared surface is increased also. Manually operated cams are incorporated into the depth-of-cut control system to retract the horizontal cutters. The levers (T) that operate the cams are shown in Figure 17.

Figure 17 also shows the front rolls (L) that hold the device in alignment on the plate. These rolls were mounted on slides and are moved into firm contact with the surfaces of the component to maintain alignment of the device during the surface preparation operation. In addition to the forward alignment rolls, two similar rolls are placed in back of the horizontal cutting units and in front of the vertical cutting unit. The rear alignment rolls (U) are visible in Figure 18, which shows the bottom of

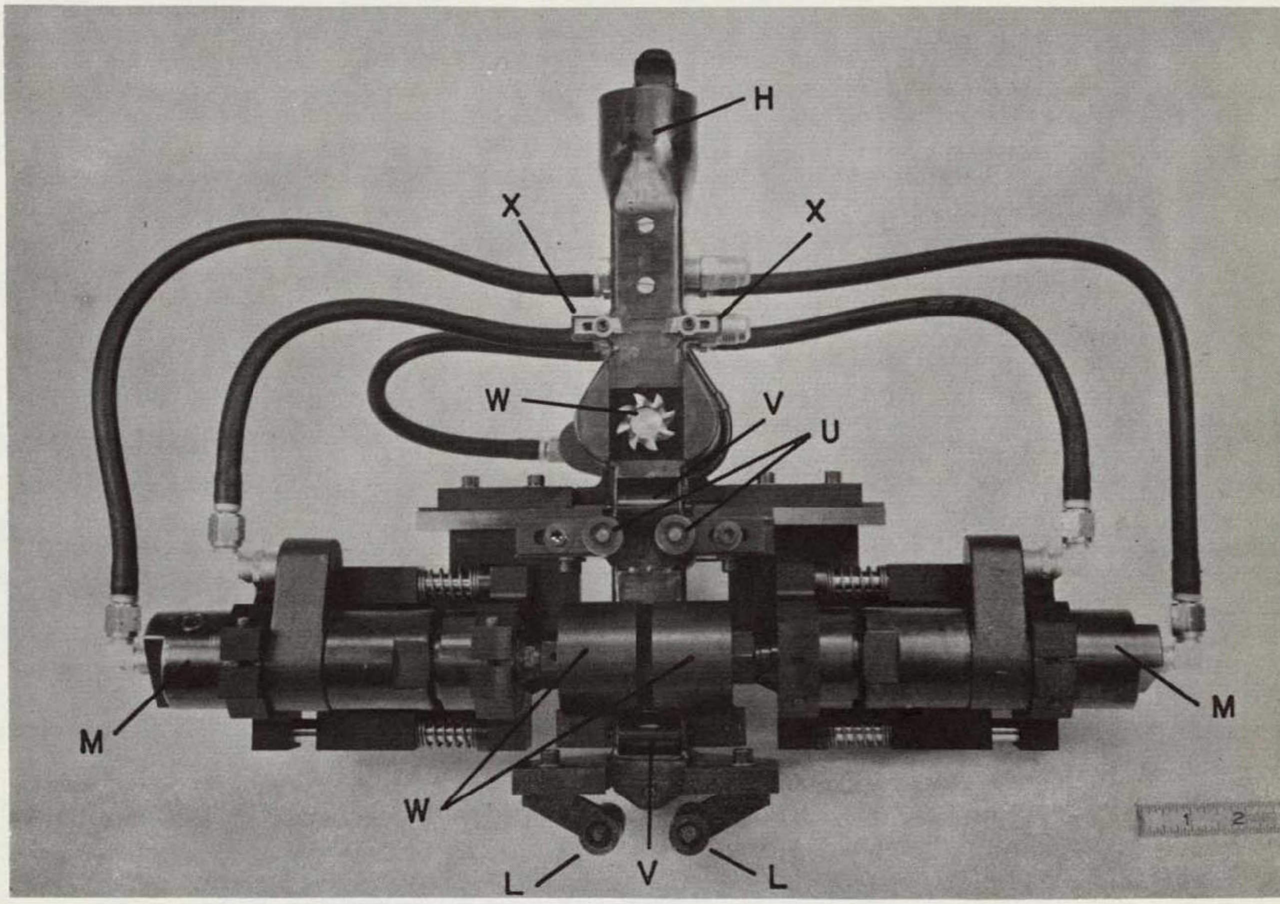


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Fig. 18 - Bottom View of Cutting Unit.

the cutting unit. Modifications of these rolls will be discussed in Section IV-A.

Two horizontal rollers (V) are incorporated into the bottom of the cutting unit to roll on the abutting edges and to maintain a constant distance between the unprepared edge and the cutter on the vertical motor. These rollers are visible in Figure 18; one roller is located immediately behind the clevis joint, and one is located immediately in front of the cutter on the vertical motor. These positions were selected so that the rollers would precede the vertical cutter and would not contact the freshly machined surface.

Additional features of the body of the cutting unit are visible in Figure 18. Two openings (W) in the bottom of the body were located so as to provide for the removal and collection of chips. One opening, which is visible in the photograph, corresponds to the location of the vertical cutter. The other opening is located under the shrouds that encircle the cutters on the horizontal motors. The shrouds are used to contain chips from the horizontal cutters and to act as ducts to direct air into the vacuum chip-collection system. Also visible in Figure 18 are two small cutting tools (X) in back of the vertical cutter. The purpose of these tools is to remove burrs that are formed at the machined edges. These cutters also required modifications and will be discussed in Section IV-A.

The weight of the cutting unit as originally designed is 37 lb, 8 oz and the weight of the drive unit is 4 lb, 10 oz. The total weight of both units is 42 lb, 2 oz. The units may be separated for mounting on the component or plate, or they may be mounted as a single unit.

Electrical and compressed air supplies are required. Electrical requirements are minimal: 110 volts to operate the drive motor, shop vacuum cleaner, and air solenoid. A compressed air supply with a capacity of 1.55 $m^3$/min (90 cfm) at a pressure of 620.5 kN/$m^2$ (90 psi).

## IV. PHASE III - EMPIRICAL EVALUATION AND MODIFICATION OF PROTOTYPE DEVICE

Initial tests with the prototype device were performed to determine operational characteristics such as alignment on plate or component edge, depth-of-cut control and adjustment, surface finish and deburring. Minor requirements for modifications became apparent in these initial tests.

### A. Modifications

Three minor modifications were made to the prototype device as a result of the initial tests. Included were improved methods to: (1) adjust the alignment rollers on the cutting unit; (2) adjust and measure the depth of cut on the horizontal motors; and, (3) deburr the corners of the plate.

#### 1. Alignment Rollers

In the initial design, the alignment rollers were manually forced against the sides of the component to achieve alignment. This original method proved to be awkward, and the rollers could not be adequately tightened for satisfactory operation.

To overcome this shortcoming, a screw adjustment was incorporated into the alignment rollers on the cutting unit. With this adjustment, the rollers can be forced together to firmly contact the component surfaces. The modification is shown in Figure 19.

#### 2. Depth-of-Cut Adjustment

In the initial design, the horizontal motors were moved manually to tilt the horizontal cutters and the angle of tilt was determined from a pointer and scale that was graduated in degrees. When this system was used to adjust the depth of cut, it was found that depth of cut was more sensitive to tilt angle than had been indicated in previous studies--an angle of 0.5° is approximately equal to a 0.13 mm (0.005 in.) depth of cut. As a result, reproducible depth-of-cut settings could not be made.

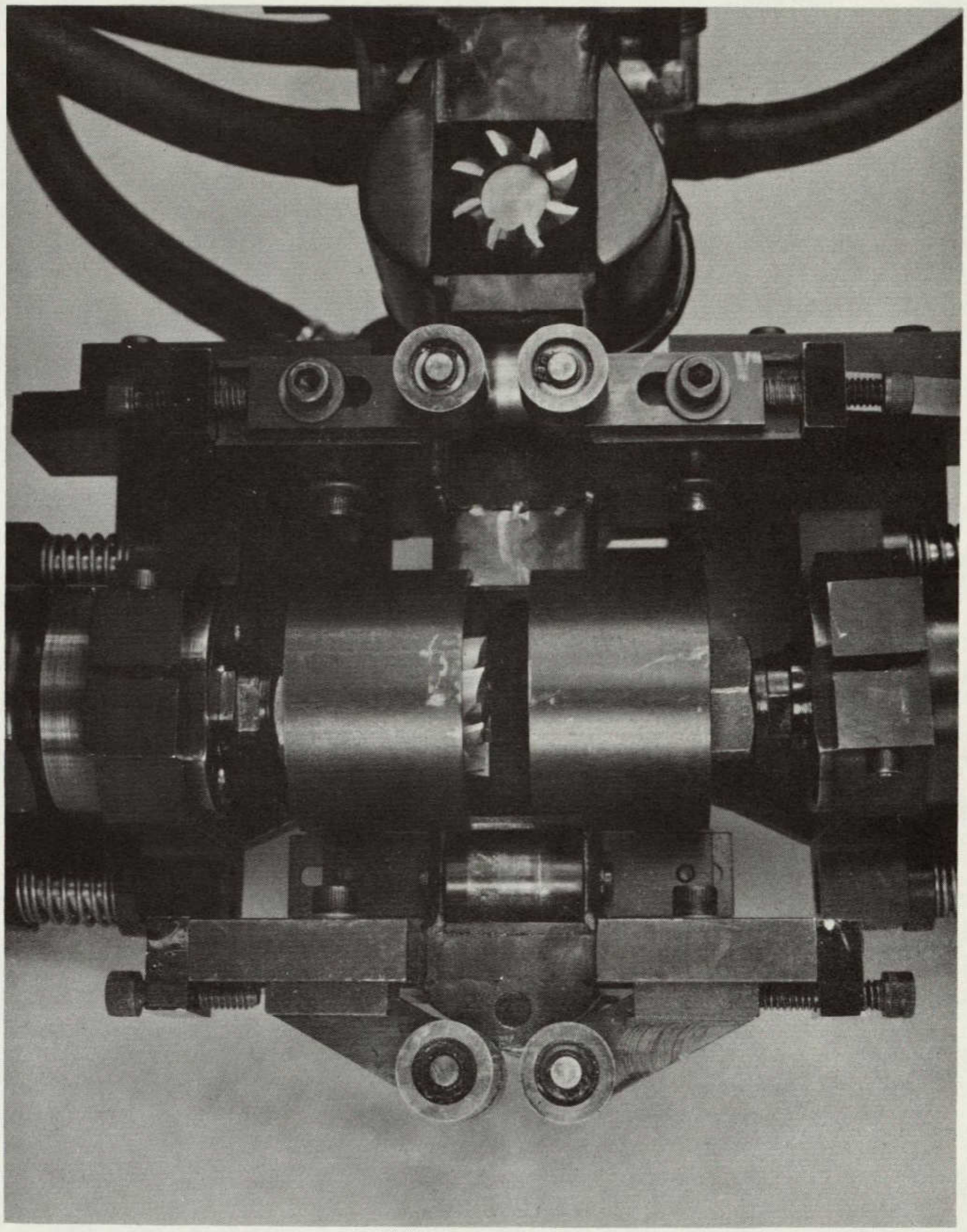

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Fig. 19 - Bottom View of Modified Cutting Unit with
Screw Adjustments for Alignment Rollers.

The mechanism was modified by inserting a cam for the purpose of adjusting the angle of the cutter and replacing the pointer with a vernier to allow accurate measurement of the angle. A photograph of the modified mechanism is shown in Figure 20.

### 3. Burr Removal Tools

The small cutting tools mounted on the aft end of the cutting unit were held in a fixed position in the initial design. During operation, however, the tools did not remove a consistent amount of metal due to variations in the thickness of the plate--at some locations they removed no metal, and at others they removed an excessive amount.

To correct this problem, the deburring tools were spring loaded to exert an approximately uniform cutting load regardless of variations in plate thickness. Also, a locking device was included so that the cutters can be retracted while the device is mounted on the plate or component.

## B. Operational Features

Detailed operational instructions are provided in the Operating and Maintenance Manual supplied with the prototype device. However, these features will be briefly summarized.

The prototype device is equipped with an air solenoid, air supply and exhaust hose, and electrical cable to extend from the unit to the solenoid and an electrical outlet. The solenoid is normally mounted at the air supply, and the hoses and cables are extended to the work area. A shop-type vacuum cleaner, which is not supplied with the device, must be attached to provide for chip removal.

Before mounting the device on the component to be prepared, it is necessary to retract the cutters, vertical alignment rolls, drive rolls, and horizontal cutter shrouds to allow the unit to be placed on the component edge. When the unit is in place, the forward and rear vertical alignment rolls are forced into con-

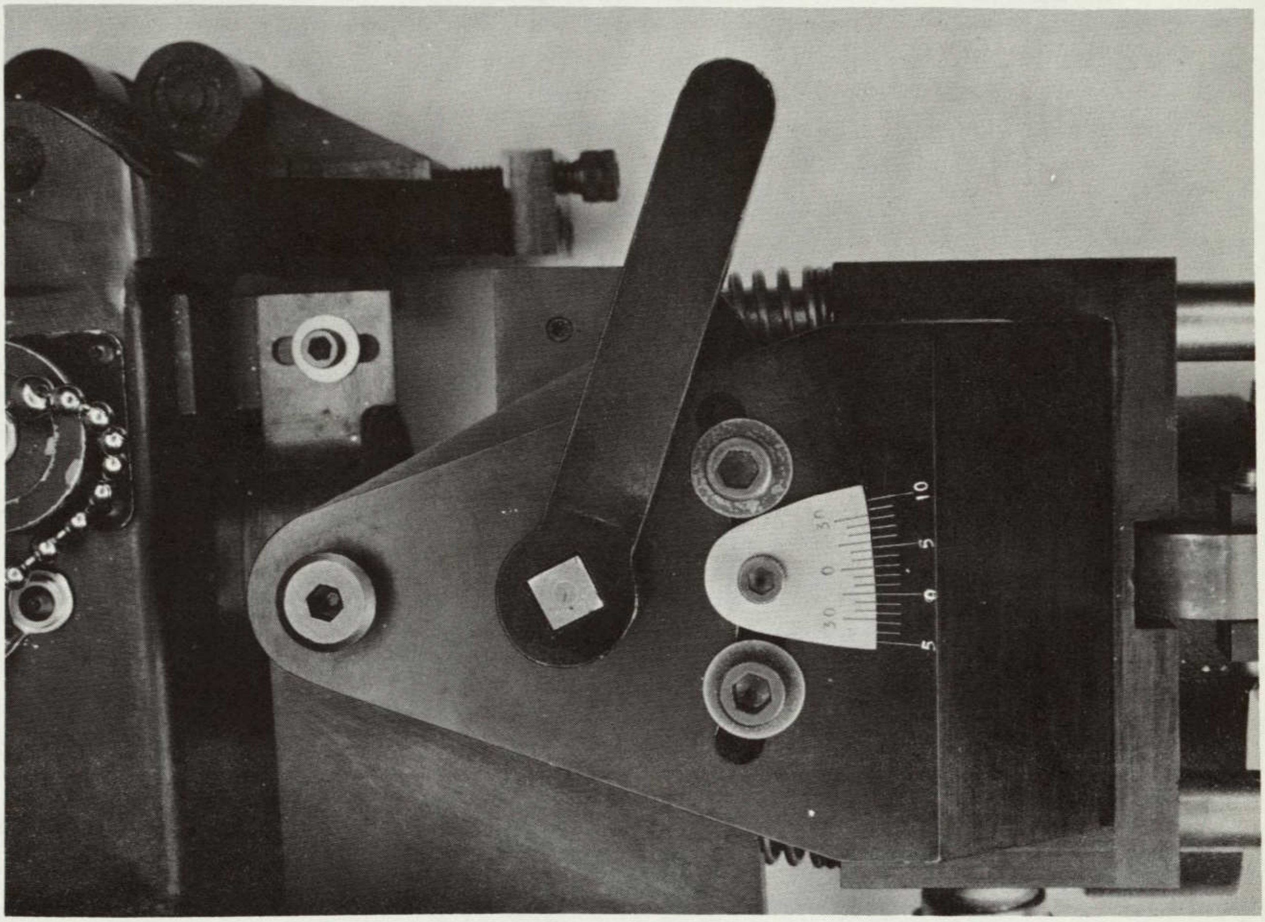

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Fig. 20 - View of Modified Cam-Operated Tilt Mechanism with Vernier for Angle Measurement.

tact with the surfaces by adjusting the screw devices on each roller; then the cap screws are tightened to maintain alignment. The entire unit is then manually traversed for a short distance along the plate to check whether excessive force is required to power the unit. If so, the guide rollers are backed slightly to allow free travel, yet maintain a positive relation to the plate. The drive rollers are then tightened against the plate. Next, the horizontal drive motors are positioned approximately normal to the surface, and the cams are rotated to allow the thrust button to contact the surface.

At this time the horizontal cutters are examined to insure that the cutting edges are not in contact with the surface. If the cutting edges are in contact with the surface, the motors must be pivoted until contact is eliminated. The horizontal motors are then adjusted vertically so that the center of the thrust button contacts the surface below the edge of the component but is within the distance that will constitute the weld-fusion zone after the part is welded. The shrouds are moved into close proximity with the surface, and the unit is then ready for adjustment of the depth of cut.

Depth-of-cut settings are made on the horizontal cutters before the milling drive motors are rotated. Depth of cut for the horizontal motors is set as follows:

(1) Rotate cams so thrust button contacts the component surface.

(2) Loosen cap screws to allow the motor to pivot.

(3) Rotate the motor to insure that cutter is not in contact with surface.

(4) Pivot motor with cam wrench until trailing edge of cutter touches the surface.

(5) Record the location of the vernier with respect to the graduations, as cutter touches plate.

(6) Retract the cutter by means of the cam handle.

(7) Increase tilt angle to correspond to desired depth of cut (approximate relationships between the tilt angle and depth of cut are presented in Figure 21).

(8) Tighten cap screws at desired setting.

Depth of cut for the vertical motor is set while the motor is running. The switch on the handle activates all air motors. Vertical adjustment is performed as follows:

(1) Loosen cap screws that release vertical slide.

(2) Turn adjusting knob to lower motor until cutter engages the edge of the component.

(3) Turn micrometer until spindle engages the stop attached to the motor mount.

(4) Retract micrometer spindle a distance corresponding to the desired depth of cut.

(5) Turn adjusting knob to move cutter into the part until the micrometer spindle is again in contact with the stop.

(6) Tighten cap screws to hold vertical motor firmly.

After the above adjustments have been made, the unit is ready for operation. The cams on the horizontal motors are then rotated to allow the horizontal cutters to engage the workpiece, and the locks holding the deburring tools in the retracted position are disengaged. At this time, all cutters are engaged with the component. The next operation is to switch the drive motor on and allow the device to traverse the edge of the component. After a short length of surface has been prepared, the drive motor is stopped, the horizontal cutters are retracted, and the air motors are stopped.

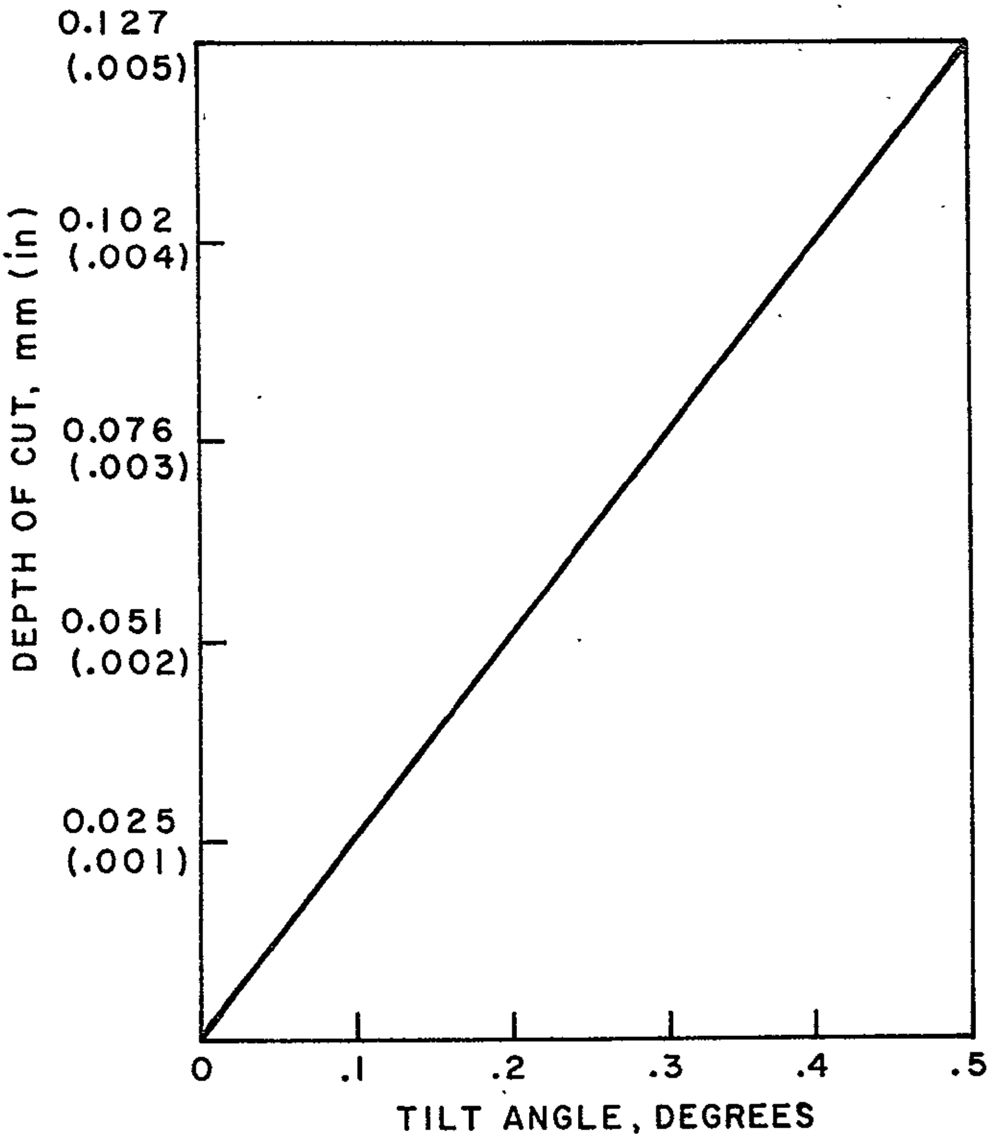



Fig. 21 Relationship Between Depth of Cut and Tilt Angle as Measured from Position Where Cutter Touches Surface

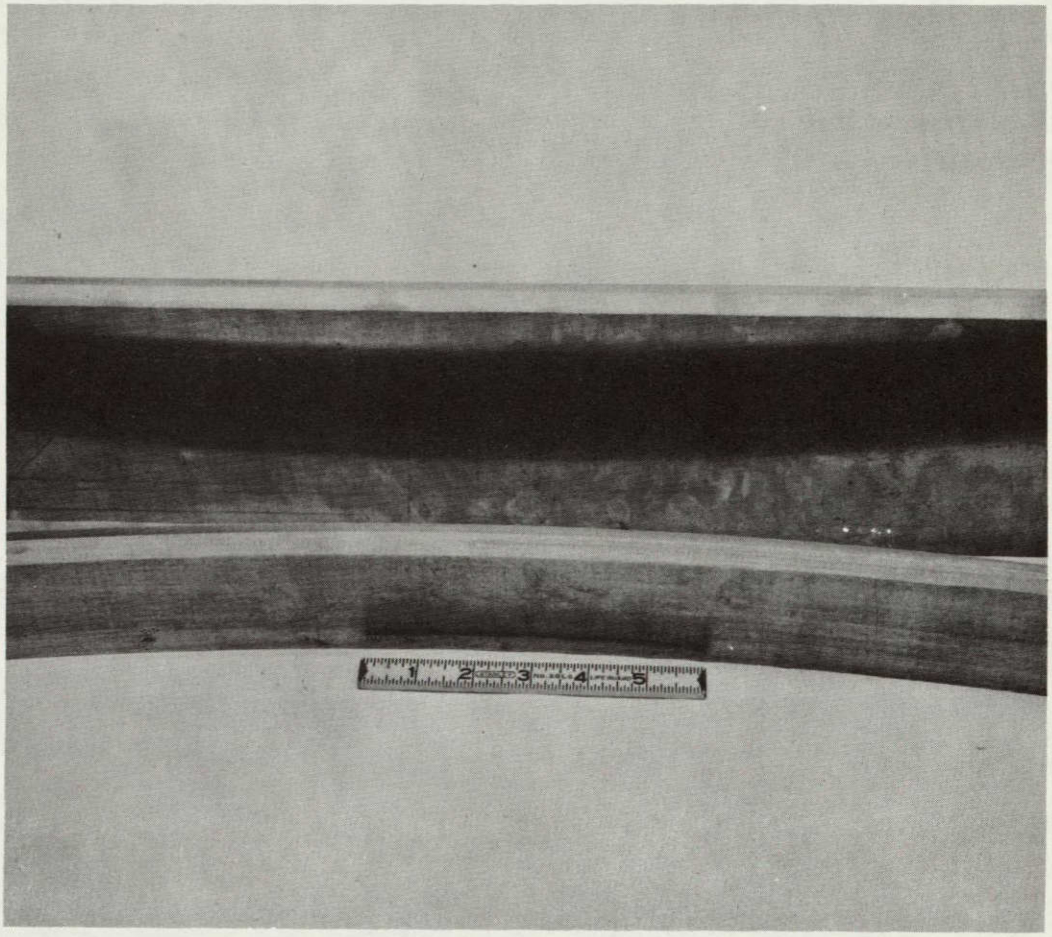
The short length of prepared surface is then measured to determine that all adjustments were properly made. Then the air motors are turned on, the horizontal cutters are engaged, and the drive unit is activated. The device is allowed to traverse the edge until the drive motor reaches the end of the plate or when preparing a cylinder until the unit returns to the starting position. The exact point for stopping on a cylindrical component depends on a number of variables that will be discussed in Section IV-D.

## C. Defect Potential of Prepared Surfaces

The most important requirement for the device is that it be capable of preparing weld surfaces to achieve a low defect potential. This characteristic was evaluated by: (1) preparing flat plate specimens with a square butt configuration from 6.3 mm (¼ in.) plate of 2014-T6 aluminum alloy; (2) machining the edges with the prototype device; (3) preparing gas tungsten-arc horizontal seam and spot welds; and (4) radiographic examination of the seam welds and visual examination of the fractured spot weld specimens. For controls, chemically cleaned and as-received material was also welded.

Plates for the welding tests were prepared as strips 101.6 mm (4 in.) to 152.4 mm (6 in.) wide and 914.4 mm (36 in.) to 1,219.2 mm (48 in.) long. The edges were milled to provide a smooth starting surface for the device. The strips were only degreased before preparing them with the prototype device. This was considered to be the most severe condition that would be encountered. The depth of cut was varied in preparing specimens. Photographs of flat and curved plates after preparation are shown in Figure 22.

In preparing the weld specimens, severe conditions were imposed to insure a critical evaluation of the defect potential of the surfaces. These severe conditions included: (1) welding in the horizontal position to entrap porosity; (2) depositing a single pass weld so that subsequent weld passes would not allow



Neg. No. 37085

Fig. 22 - Plates with Edges Prepared by Prototype Device.

porosity to be released from the joint; and (3) depositing a partial penetration weld (50-70% of the plate thickness) to provide surfaces for the nucleation of porosity. All welds were made without filler wire to eliminate a potential variable due to filler wire surface contamination. Long tack welds were required at the center and end of the plate to prevent tack weld cracks and to maintain alignment. A photograph of the welding setup is shown in Figure 23.

Weld parameters for the seam welds are listed below:

| | |
|---|---|
| Arc voltage | 12 volts |
| Current | 160 amperes |
| Travel speed | 431 mm/min (15 ipm) |
| Electrode | tungsten-2% thoria |
| Diameter | 4 mm (5/32 in.) |
| Taper | 32° |
| Flat | 2.4 mm (3/32 in.) |
| Shielding | |
| Nozzle Diameter | 15.9 mm (5/8 in.) |
| Nozzle to work | 4.8 mm (3/16 in.) |
| Gas | helium |
| Flow rate | 1.42 $m^3$/hr (50 cfh) |
| Dew point | -40°C (-40°F) |

Weld parameters for the fusion spot-weld tests are listed as follows:

| | |
|---|---|
| Arc length | 1.6 mm (1/16 in.) |
| Current | 280 amperes |
| Electrode | tungsten-2% thoria |
| Diameter | 4 mm (5/32 in.) |
| Taper | 32° |
| Flat | 2.4 mm (3/32 in.) |
| Shielding | |
| Nozzle diameter | 15.9 mm (5/8 in.) |
| Nozzle-to-work distance | 4.8 mm (3/16 in.) |
| Gas | helium |
| Flow rate | 2.84 $m^3$/hr (100 cfh) |
| Dew point | -40°C (-40°F) |

Radiographic examinations were performed on the seam welds. Welds in the as-received and chemically-cleaned plates exhibited severe continuous porosity along the entire weld. Fracture surfaces from weldments in a chemically cleaned specimen are shown in Figure 24. These areas are typical of the entire weld length.

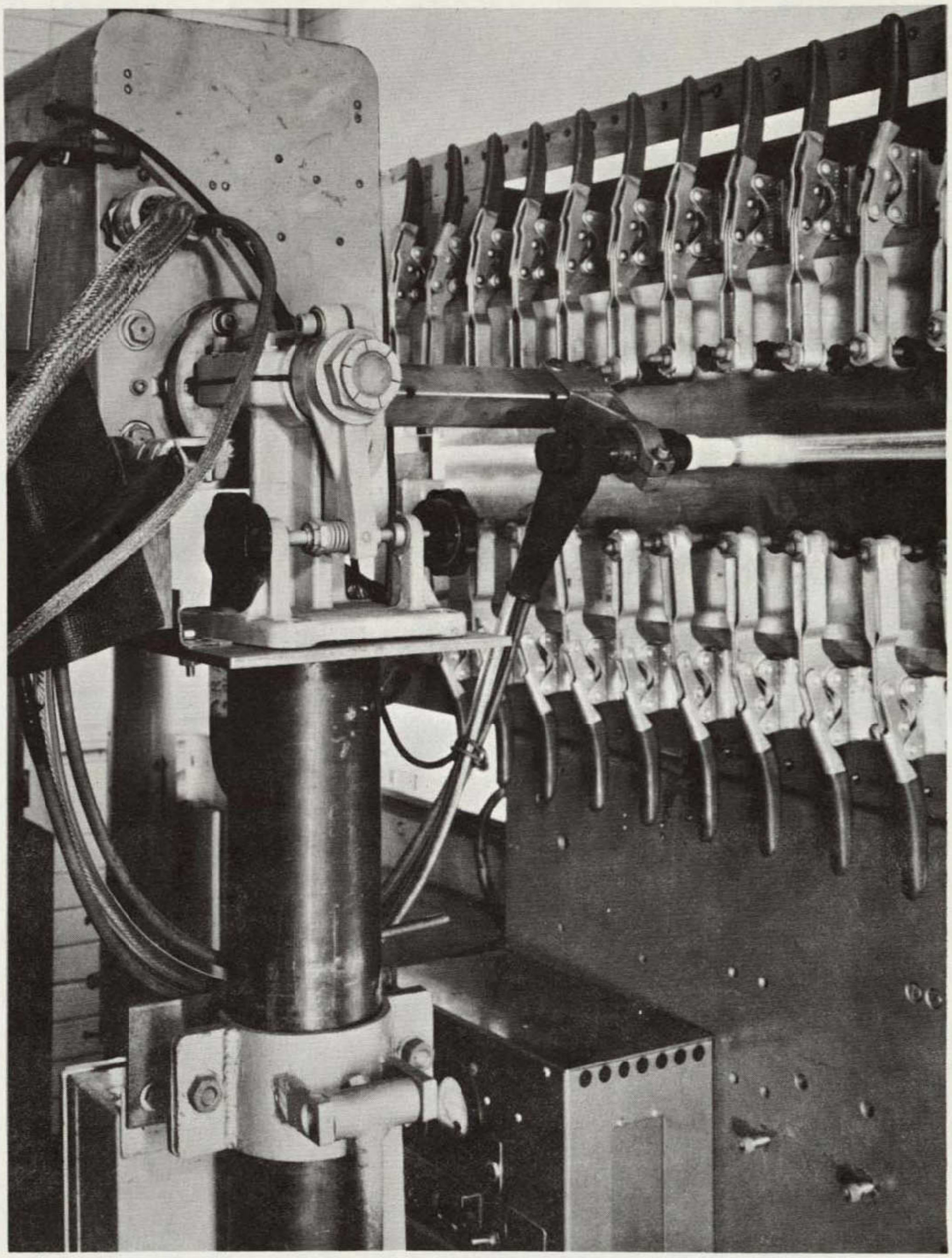


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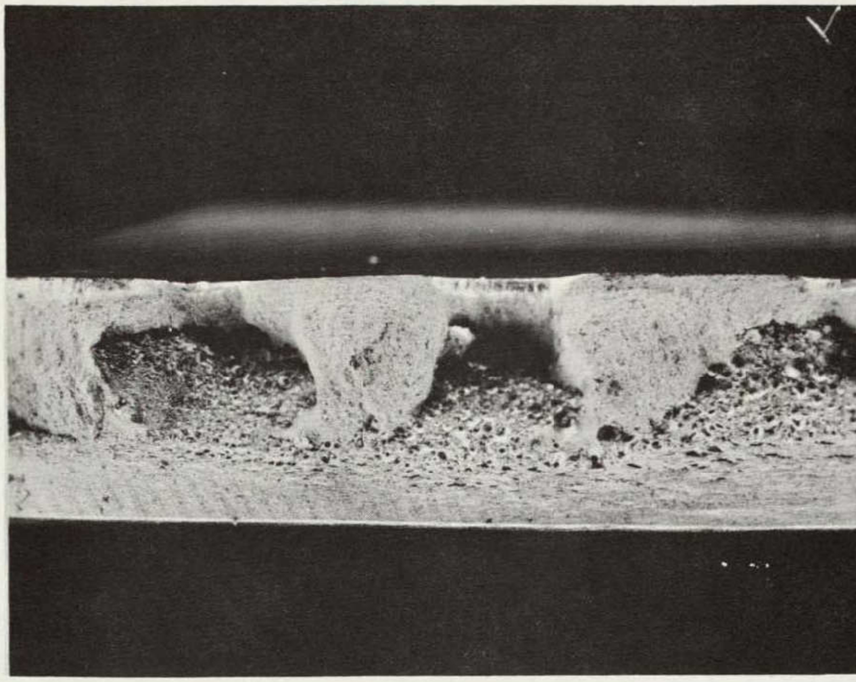
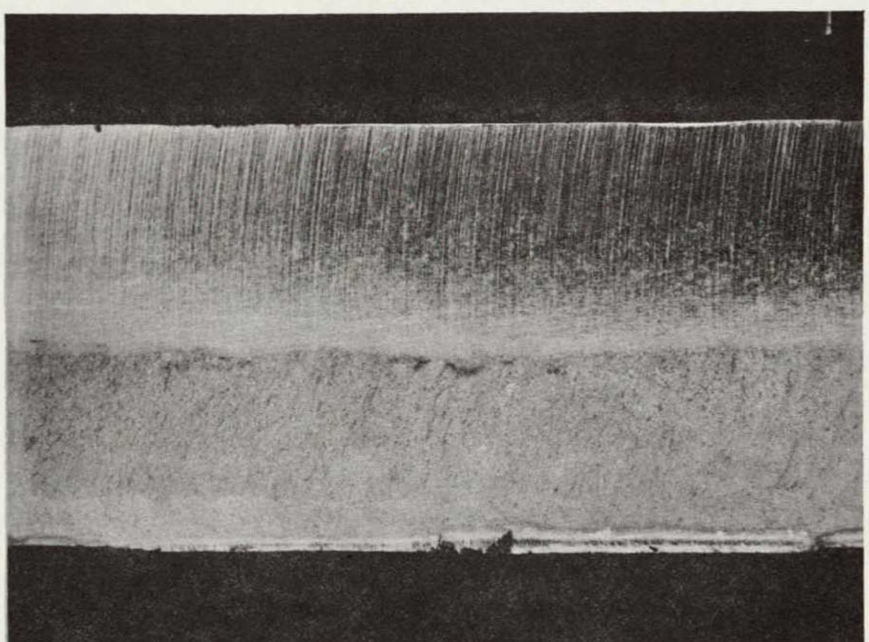
Fig. 23 - Setup for Welding in Horizontal Position.



Neg. No. 37076 5X

Fig. 24 - Fracture Surface of Weld in Chemically Cleaned Plate; Contains Numerous Pores.



Neg. No. 37079 9X

Fig. 25 - Fracture Surface of Welds in Typical Prepared Plate; Contains Only Scattered Fine Porosity.

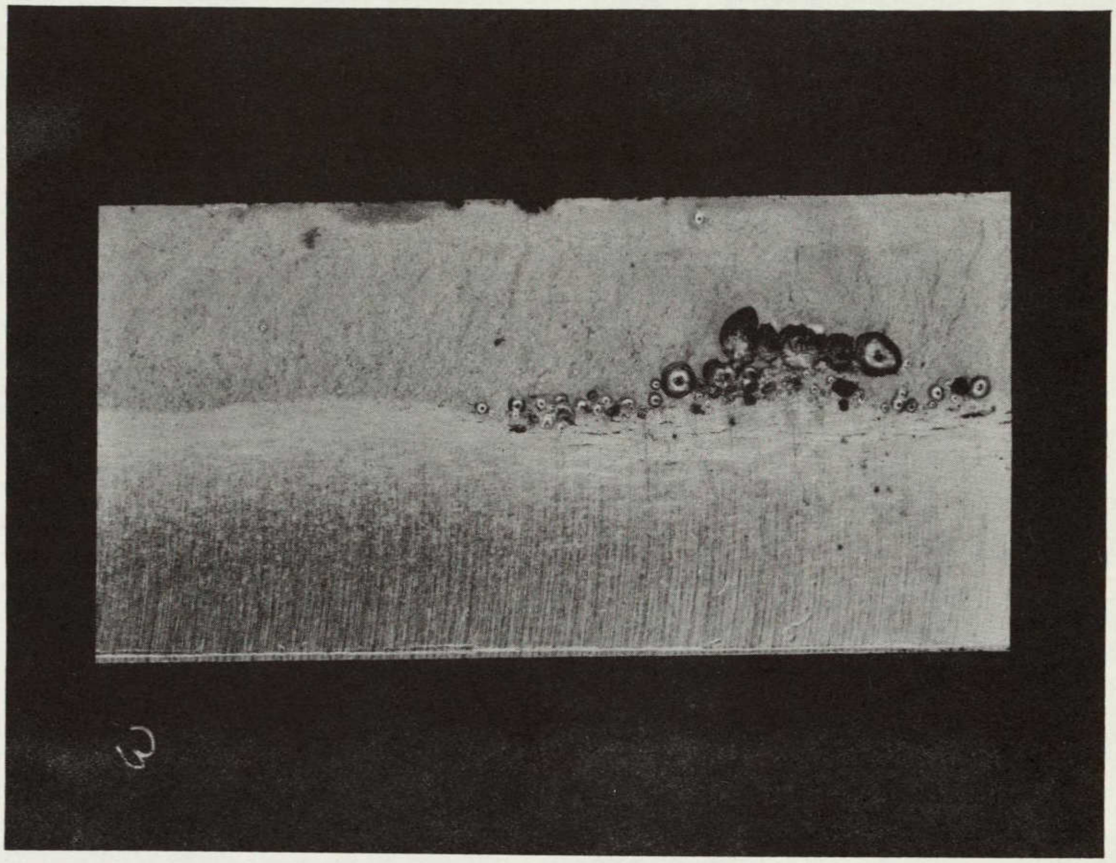
The weld defect potential of specimens prepared with the prototype device was low except for areas at and near the tack welds. Areas which were not associated with tack welds contained scattered fine porosity, primarily 0.254 mm (0.010 in.) in diameter with one 0.762 mm (0.030 in.) pore. A typical weld fracture is shown in Figure 25; weld soundness in prepared specimens greatly exceeded that for chemically cleaned plates.

Areas associated with tack welds contained scattered and clustered fine porosity. This porosity is attributed to the techniques used to prepare and clean the tack welds. The tack welds were made at the same settings used for the weld, and were long--101.6 mm (4 in.)--to prevent cracking. After tacking, the tack welds were wire brushed and the primary weld was traversed along the entire length of the plate; thus, the tack welds were rewelded and all surface contamination present on the tack weld was introduced into the weld fusion zone. Weld fracture from a tack weld area is shown in Figure 26.

Fusion spot-weld tests were performed by placing the adjacent surfaces in contact and melting the spot. Due to the concavity of these surfaces (Figure 27), it was difficult to achieve intimate contact.

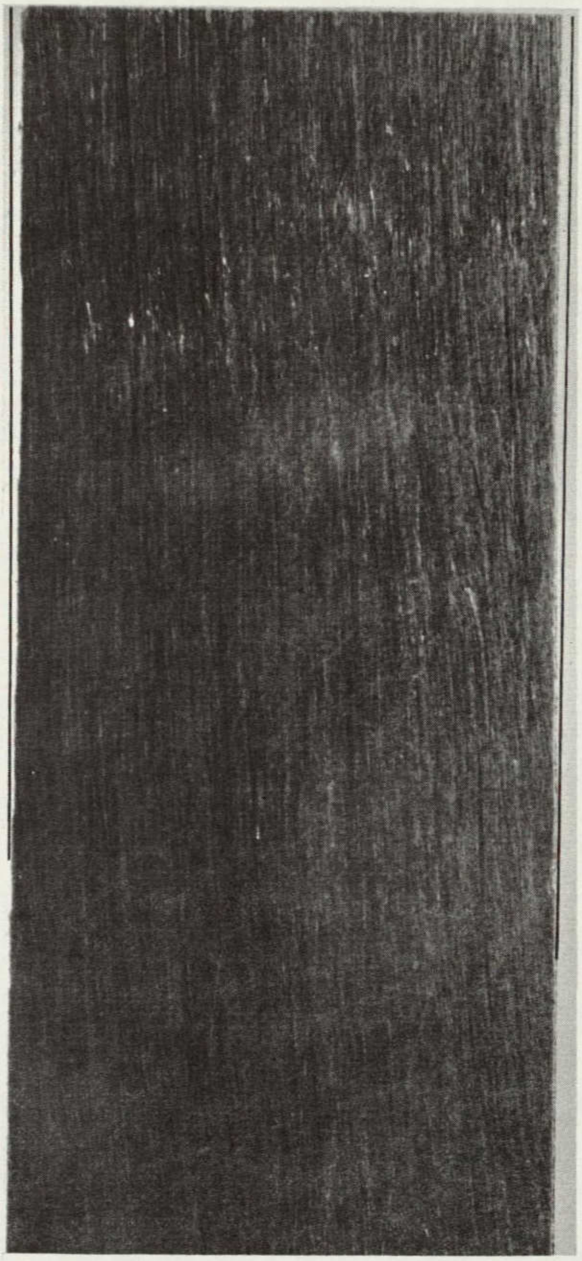
Test results from the fusion spot welds were erratic. Some spot welds were practically defect free, as shown in Figure 28, and had ratings of 1 to 5. Others, however, exhibited a considerable amount of what appeared to be oxide folds (Figure 29) in larger amounts than had been observed previously with the test on machined surfaces.

It was believed that the oxide fold defects were influenced by the gap that existed between the plate surfaces. To verify this, specimens were machined with flat surfaces to allow intimate contact. Some were welded with the surfaces in contact while others were welded with shim stock between the surfaces at the back side to provide an air gap in the interior of the specimen. Results from these tests are summarized below:



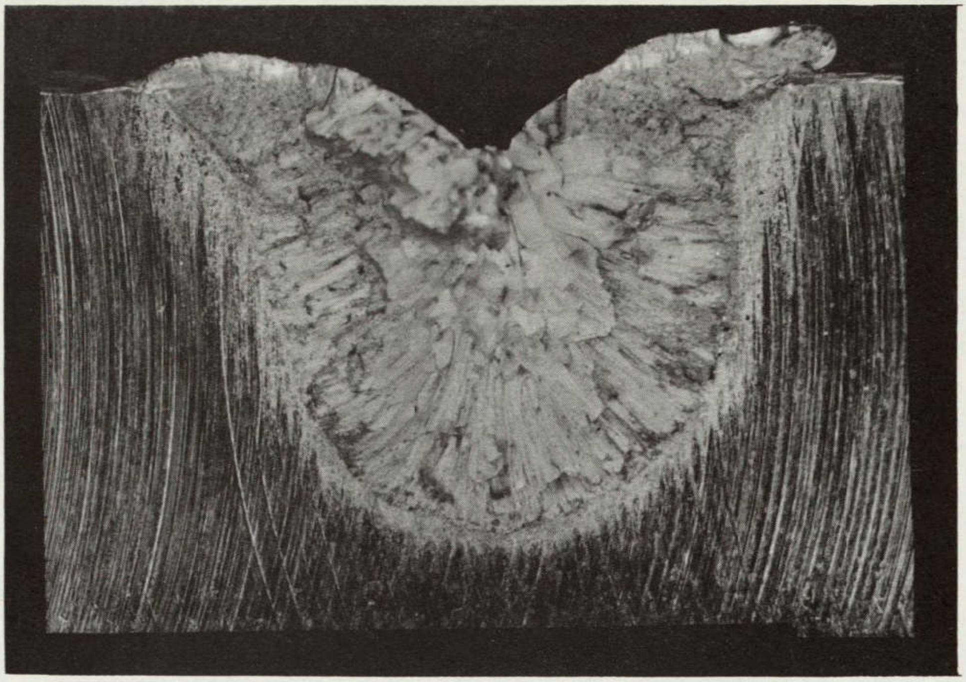
Neg. No. 37078 9X

Fig. 26 - Fracture Surface of Weld in Tack Weld Area of Prepared Plate; Contains Cluster of Fine Porosity.



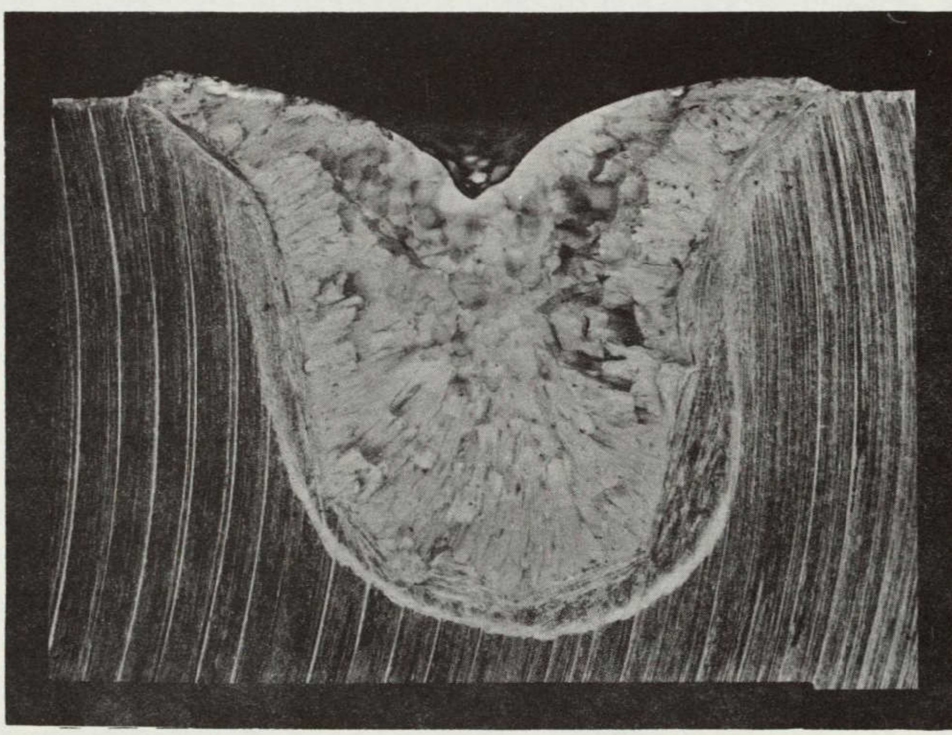
Neg. No. 37084 11X

Fig. 27 - End View of Prepared Edge Showing Concave Surfaces Resulting from 0.0508 mm (0.002 in.) Depth of Cut: lines project location of original surface.



Neg. No. 37081 6X

Fig. 28 - Fusion Spot-Weld Test from Prepared Sample Showing Low Defect Potential.



Neg. No. 37080 6X

Fig. 29 - Fusion Spot-Weld Test from Prepared Sample Showing Apparent Oxide Folds.

| Gap | Remarks |
|---|---|
| 0 | All welds excellent |
| 0.508 mm (0.002 in.) | Oxide folds in one weld |
| 1.016 mm (0.004 in.) | All welds excellent |
| 1.524 mm (0.006 in.) | Oxide folds in three welds |
| 2.032 mm (0.008 in.) | Oxide folds in all welds |

These results appear to verify the belief that the air gap is responsible for the apparent oxide folds and that the defect potential of the prepared surfaces is low.

## D. Adaptability of Prototype Device to Fabrication Requirements

A number of target requirements for the prototype device were listed in the Introduction of the report. These requirements as they are related to performance of the prototype device are discussed below:

### 1. Preparation of Surfaces Adjacent to Weld

One requirement is that the prototype device will prepare the abutting edges of the weld grooves and 25.4 mm (1 in.) widths on the adjoining surfaces.

The prototype device is designed to prepare abutting surfaces and over 25.4 mm (1 in.) widths on adjacent surfaces. However, the width that is prepared will vary with each specific application due to the shape of the cut that is made. The technique used to control depth of cut on the adjacent surfaces results in a concave surface as shown in Figure 27. The location of greatest depth of cut corresponds to the centerline of the cutter or location of the thrust button, and width of cut varies with the location of the thrust button and depth of cut. Therefore, if dimensional tolerances are critical, requiring small cuts and maximum depth of cut near the abutting surfaces, preparation of adjacent surfaces 1 in. away from the edge is not recommended.

## 2. Component Configurations and Position

Other requirements are that the system be adaptable to longitudinal and circumferential surfaces on cylinders and to elliptical and hemispherical domes positioned for welding in the horizontal, vertical, inclined curved positions, and in combinations of these positions.

Most evaluations of the device were performed on flat plate and curved plates with constant radii of curvature. Both of these geometries, which represent longitudinal and circumferential surfaces on cylinders and hemispheres are readily prepared with the prototype device.

The device also can be used to prepare parts with varying radii, such as elliptical domes; but if the change in radius is too great, it is necessary to readjust the alignment rolls on the cutting unit and angle of tilt on the horizontal cutters to compensate for the change in curvature. Adjustments of the aligning rolls are necessary to prevent binding as the radius decreases or loosening as it increases. Changes in the angle of tilt are necessary to maintain a constant depth of cut.

When preparing a part with varying radii, tests should be performed to determine if intermediate adjustments are necessary. First, the unit should be traversed around the part, without cutting, to determine if it binds or becomes loose. If either condition is encountered, these locations should be marked on the part so that the device can be stopped and readjusted during the surface preparation operation. Likewise, the tilt angle where the horizontal cutters touch the surface should be determined at various locations around the part. When this tilt angle changes a sufficient amount to change the depth of cut an unacceptable amount, the location should be marked for intermediate change. After the need for and location of intermediate changes are established, the part is machined, stopping at the prescribed locations and performing the required adjustments.

The device has a considerable tolerance for changes in radii, but sufficient tests were not performed under controlled conditions to establish conclusively the variation in radius that can be tolerated before readjustments are required. Further work should be performed to define tolerable limits without need for intermediate adjustments.

During the design of the prototype device, one concept was considered which would eliminate the need for readjusting the alignment rollers. This concept was to attach the rollers in pairs and to caster the mount so that the device would travel on surfaces with changing radii but uniform thickness without the need for adjusting the distance between the rollers. This concept was not adopted, however, because of the possibility of less rigidity in the alignment rolls and increased tool chatter.

The device was used to prepare plate edges with the plates in the horizontal welding position (Figure 30), downhand welding position (Figure 31), and vertical welding position (Figure 32). When simulating the lower subassembly of a part in the horizontal welding position, the device maintains contact with the plate due to gravity and the operator does not need to hold the unit. With parts in position for downhand welding, manual force is adequate to hold the device in contact with the surface of the part. Likewise the same technique is satisfactory for the vertical position with the device moving down the component.

A technique was not developed for turning the device upside down and machining in the mode that simulates the upper subassembly of a component in the horizontal welding position. It would be possible to prepare edges in this mode by designing a counterbalanced holding fixture for supporting the device with a crane. The purpose of the counterbalance would be to provide upward force to hold the device in proper contact with the surface of the part. However, considerable problems could be expected in coordinating crane travel with travel of the device. For horizontal welds it is recommended that the surfaces of the upper subas-

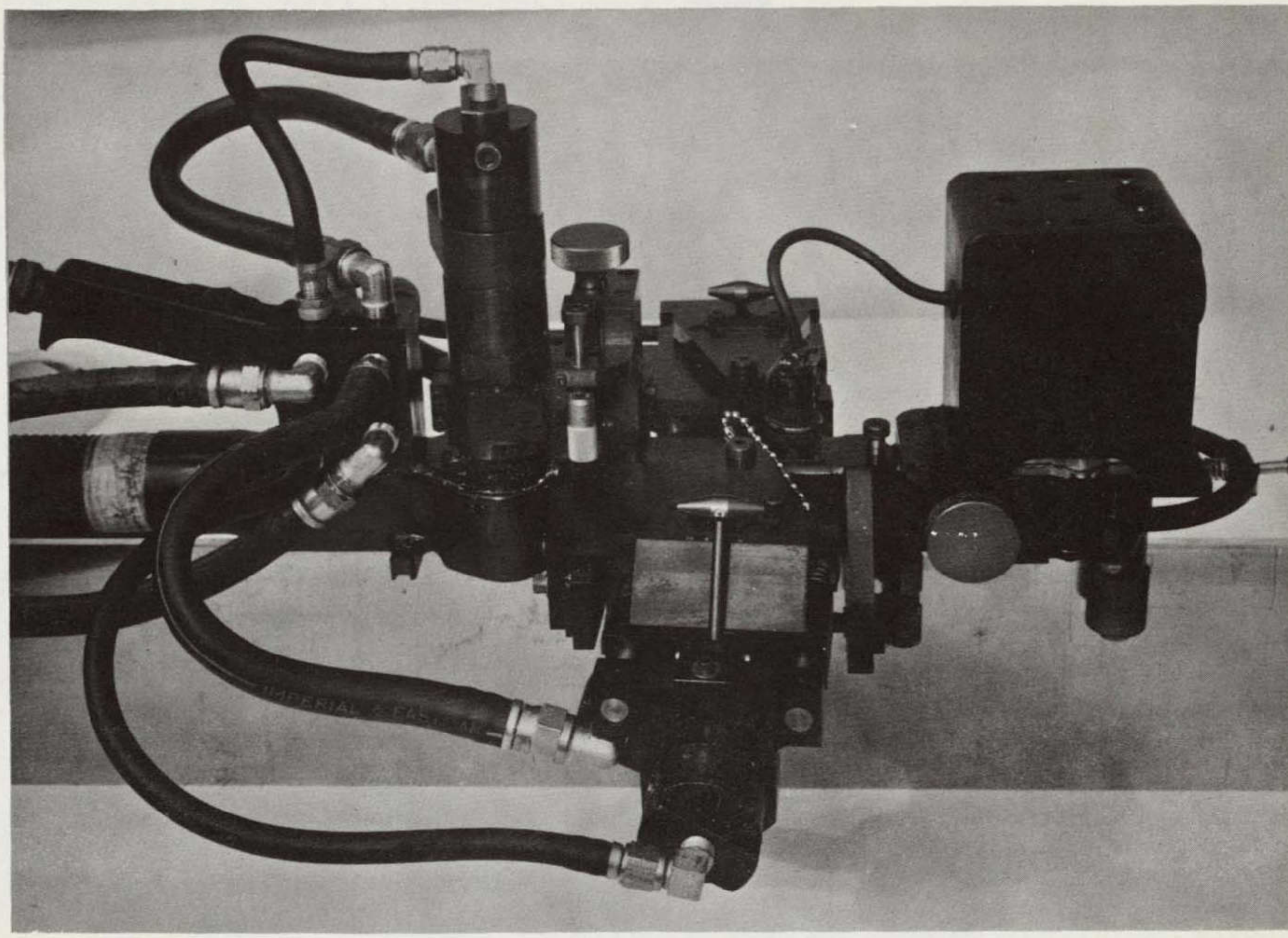


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Fig. 30 - Unit in Position for Preparing Lower Part of an Assembly to be Welded in Horizontal Position.

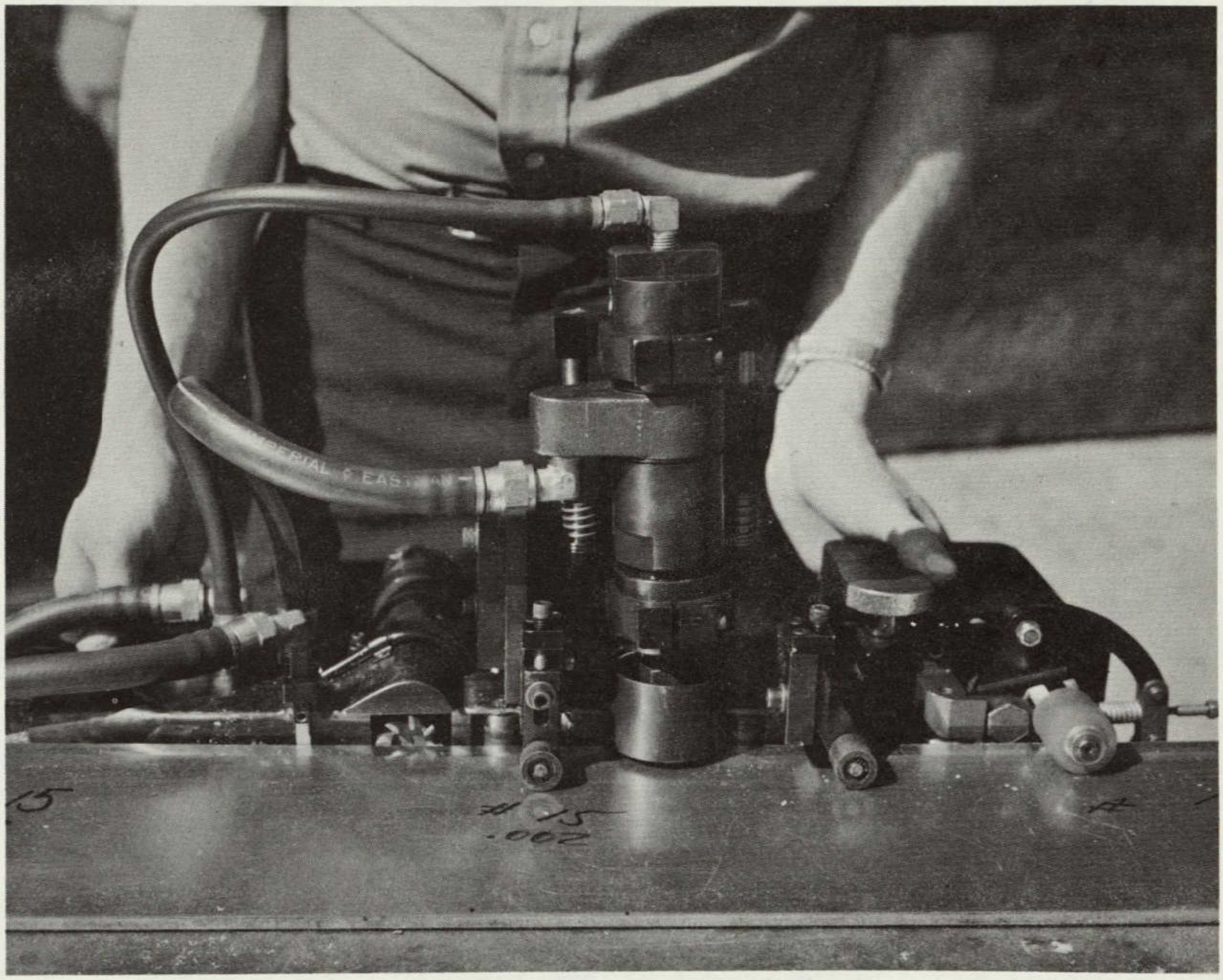

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Fig. 31 - Method for Holding Device on Plate for Preparing Surfaces in Down-Hand Welding Position.

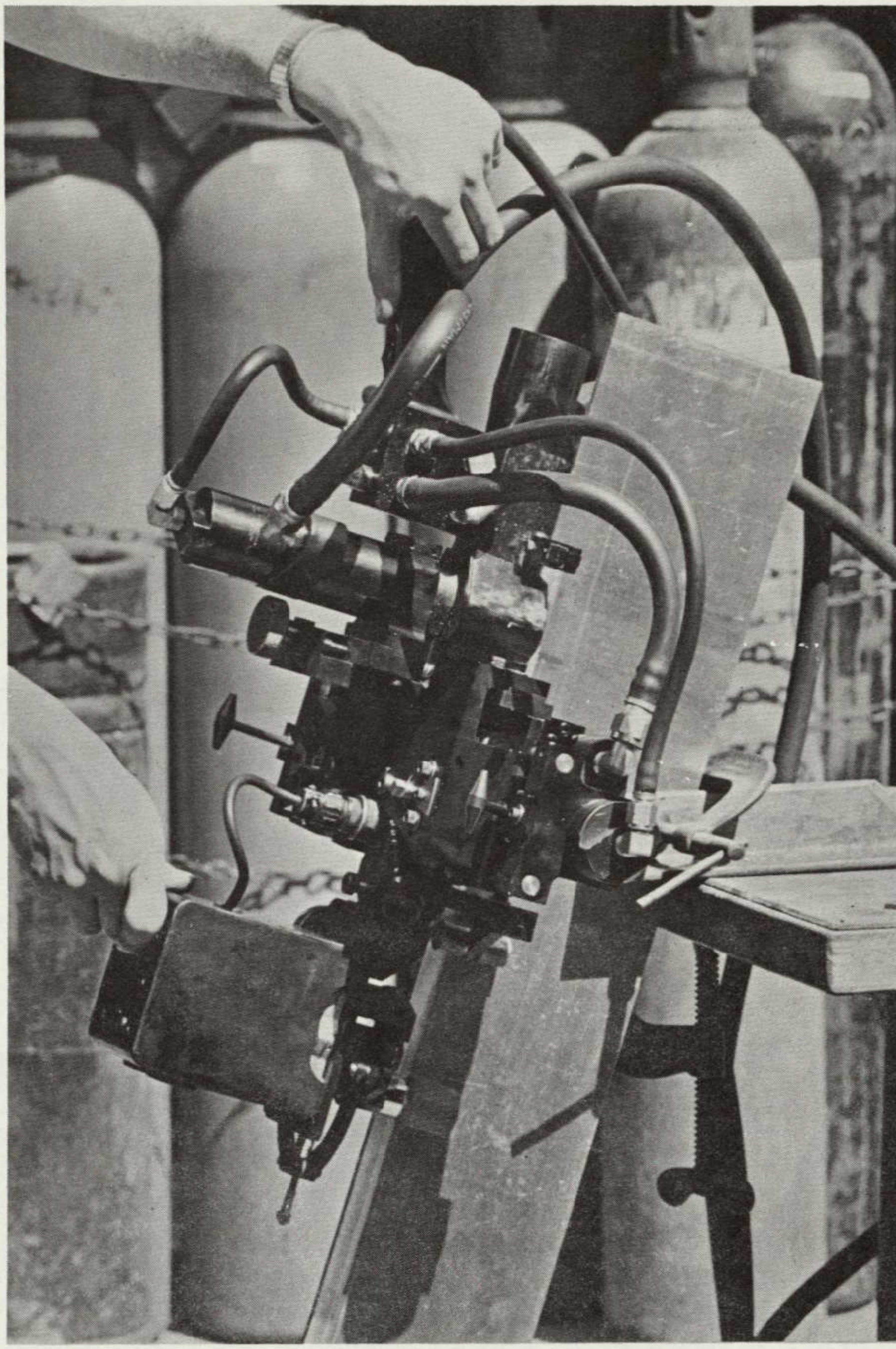


Fig. 32 - Method for Supporting Device in Preparing Surfaces in Vertical Welding Position.

sembly should be prepared while it is in a position that simulates the position of the lower subassembly.

### 3. Groove Geometry

Another requirement was to prepare all standard configurations: square butt, single- and double-V grooves, and single-U joints.

The prototype device was designed and fabricated to prepare square butt joint configurations. However, the device can be adapted to single-U joint configurations by changing cutters on the vertical motor and by moving the motor off center. Such an adjustment was incorporated into the device. For single-U configurations, the vertical cutter must be ground to conform to the U configuration. In preparing such joints two passes of the device are required: one to prepare the U and one to prepare the weld land and adjacent surfaces. For this latter pass, all operations are conventional except that the horizontal motor on the U side of the joint is set at a lower position than on the other side.

During the design of the prototype device, methods for providing adjustments to prepare single and double V joints were studied. Such adjustments can be provided by incorporating mechanisms to tilt the vertical or horizontal cutters in the vertical plane to machine the bevel. However, providing means for these adjustments on the prototype device was considered undesirable because the weight of the unit would be increased and the rigidity of the unit and chip removal system would be jeopardized. Therefore, a decision was made to design and fabricate the unit without the vertical adjustments required for bevel joints.

Two techniques can be used for preparing V joints. One is to fabricate a second cutting unit, such as that sketched in Figure 33, to hold two milling motors with adjustments to allow setting the cutters at various angles to prepare beveled plate. We consider this the most desirable approach. The other technique

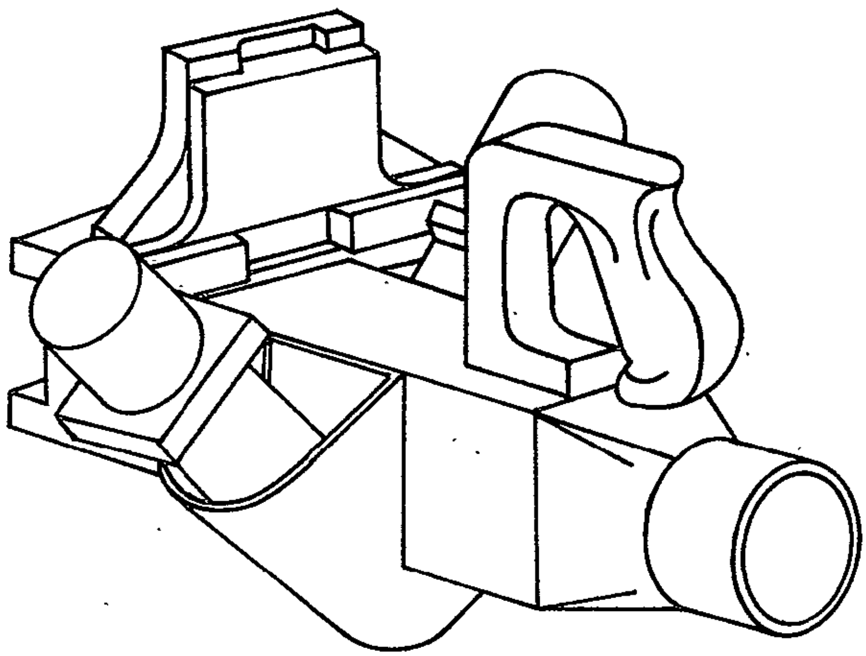


Fig. 33 Sketch of Proposed Device for Preparing Bevels on Vee Joints

is to incorporate the required adjustments in an advanced model of the current device. This latter approach would complicate the unit greatly.

## 4. Depth of Cut

Another requirement was that the metal removal be a minimum of 0.127 mm (0.005 in.)

The device was designed and powered to remove metal at depths in excess of the requirement. However, in preparing surfaces adjacent to the abutting edges, a total in excess of 0.254 mm (0.010 in.) will be removed if this requirement is fulfilled. For some components, the removal of this amount of metal cannot be tolerated. Therefore, the unit was designed so that cuts on adjacent surfaces can be made repodücibly as shallow as 0.0508 mm (0.002 in.) and in excess of 0.127 mm (0.005 in.) if desired.

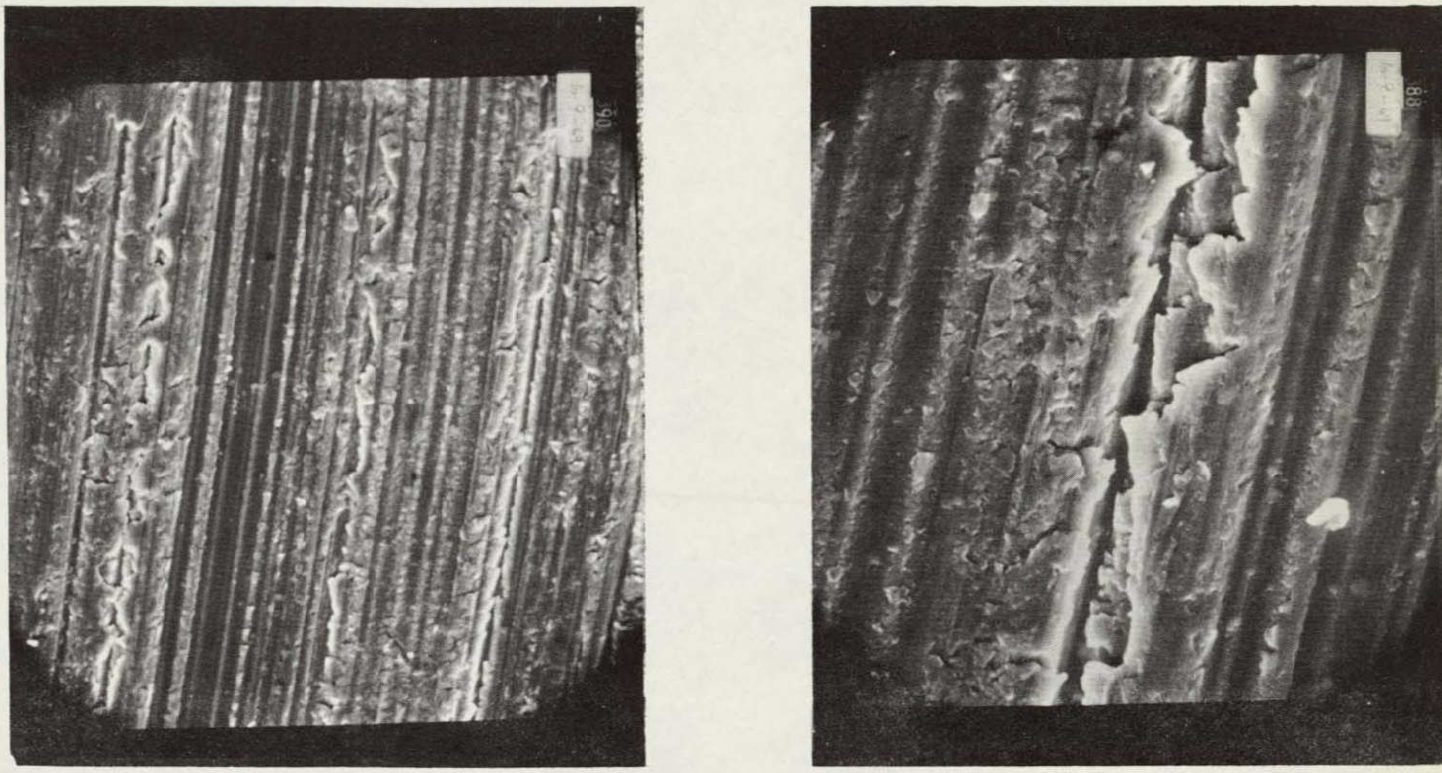
## 5. Surface Roughness and Smearing

Requirements for surface roughness were specified to be a maximum of 5.08 μm (200 μin.) with a minimum of smeared metal.

A Proficorder was employed to measure surface roughness on typical prepared surfaces. Roughness measurements of 2.54 to 4.85 μm (100 to 191 μin.) rms were calculated. The rms value is in the required range. It should b e noted, however, that rms values normally are one-fifth to one-third the value of the maximum size of irregularities in the surface. Therefore, irregularities that exceed the rms value can be expected.

The scanning electron microscope was used to examine surfaces for evidence of smeared metal. Examinations were made on the abutting edges and adjacent surfaces.

A change in cutting speed for the vertical motor --that is, the abutting edges--was made on the basis of these examinations. Initially the vertical motor was operated at 18,000 rpm, resulting in abutting edges with the surface characteristics shown in Figure 34. These surfaces contained the normal tears and pits that char-




SEM 390 (a) 300X

SEM 388 (b) 1000X

Fig. 34 - Scanning Electron Micrographs of Abutting Edge Machined at 18,000 rpm; Contains Undesirable Folds.

acterize all machined surfaces, but also contained numerous folds which were potential traps for contaminants and were considered undesirable.

In an effort to improve the surface of the abutting edges, the speed of the vertical motor was reduced to 4500 rpm. Surfaces produced at the lower rpm were definitely superior to those achieved at the higher speed as shown by the scanning electron micrographs in Figure 35. These latter surfaces contain numerous tears and pits, but do not contain the overlap areas observed previously and show evidence of only a very small amount of smeared metal. These latter surfaces are considered to be extremely good and acceptable for welding operations.

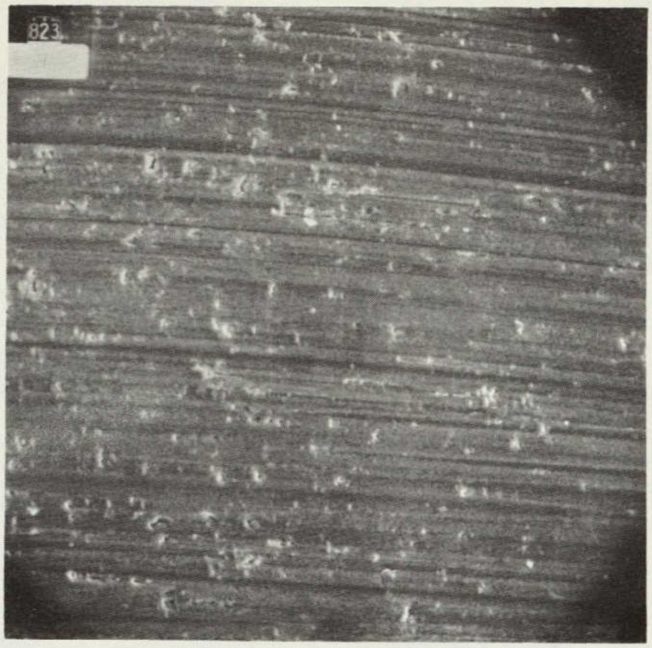
Prepared surfaces adjacent to the edges were examined at two locations; near the edge at maximum cut depth and away from the edge at lower cut depths. Scanning electron micrographs of typical surfaces near and away from the edge are shown in Figures 36 and 37, respectively. The surfaces contain the normal tears and pits, and only a small amount of smeared metal was observed.

6. Component Thickness

The device was designed to prepare surfaces ranging in thickness from 2.54 mm (0.1 in.) to 25.4 mm (1.0 in.) as specified in the requirements. From tests performed on the thinner material, it was observed that thin components should be carefully fixtured to stiffen the structure near the surfaces to be prepared. For the thickest plate, the device is satisfactory if the thickness is sufficiently uniform so that the alignment rollers do not bind on the plate.

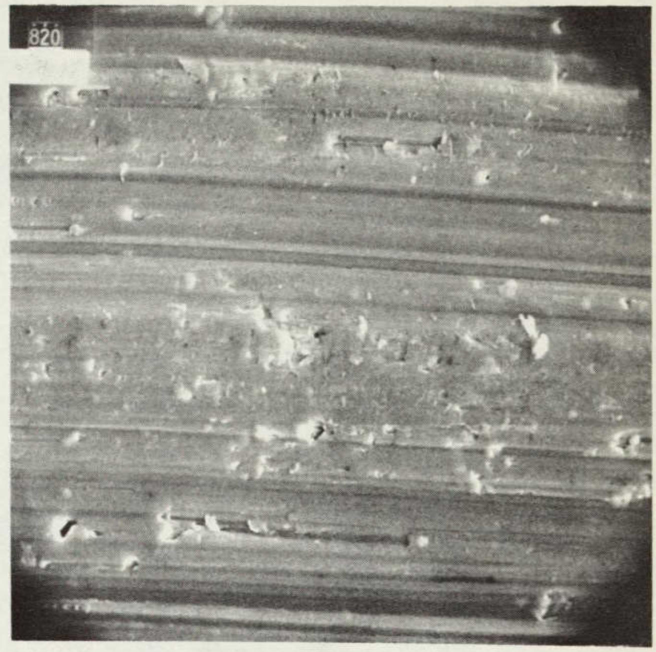
7. Lubricants and Manual Work

The device was developed to dry-machine aluminum surfaces. This is an important requirement in preparing surfaces with a low defect potential.



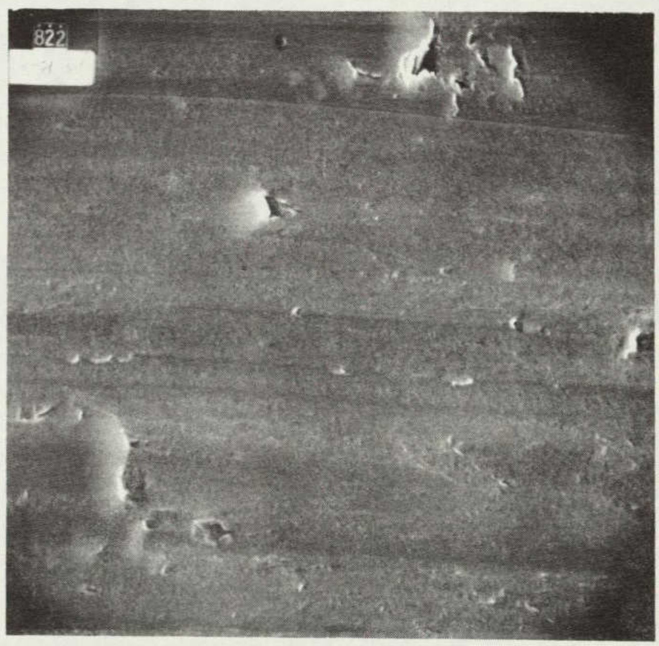

SEM 823 300X

(a)




SEM 820 1000X

(b)

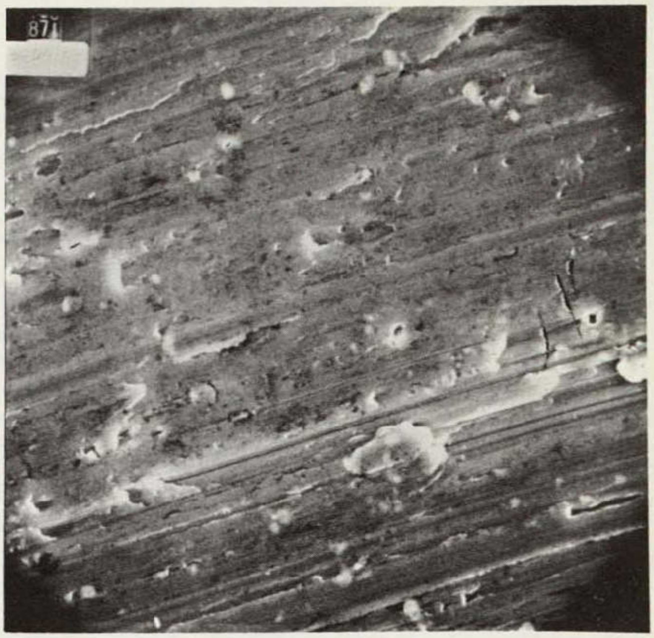



SEM 822 3000X

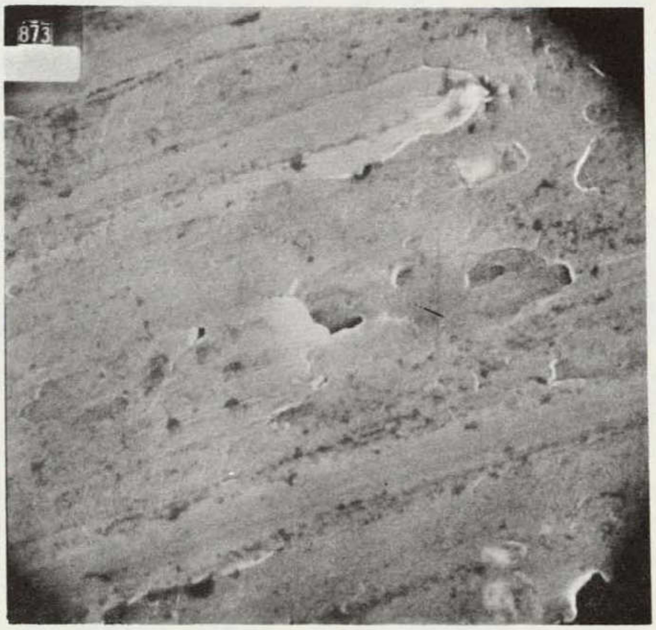
(c)

Fig. 35 - Scanning Electron Micrographs of Abutting Edge Machined at 4500 rpm; Surface Extremely Good.

SEM 872 300X
(a)

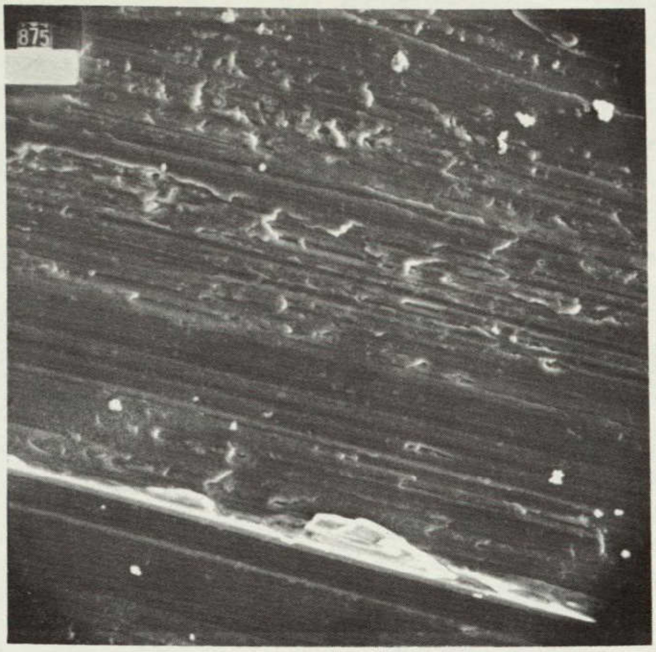


SEM 871 1000X
(b)



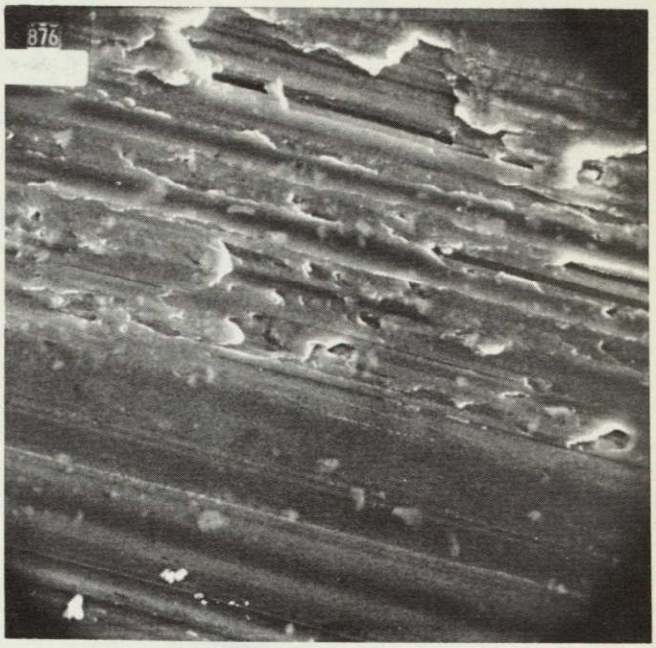
SEM 873 3000X
(c)

Fig. 36 - Scanning Electron Micrographs of Adjacent Surface Near Abutting Edge; Surface is Acceptable.



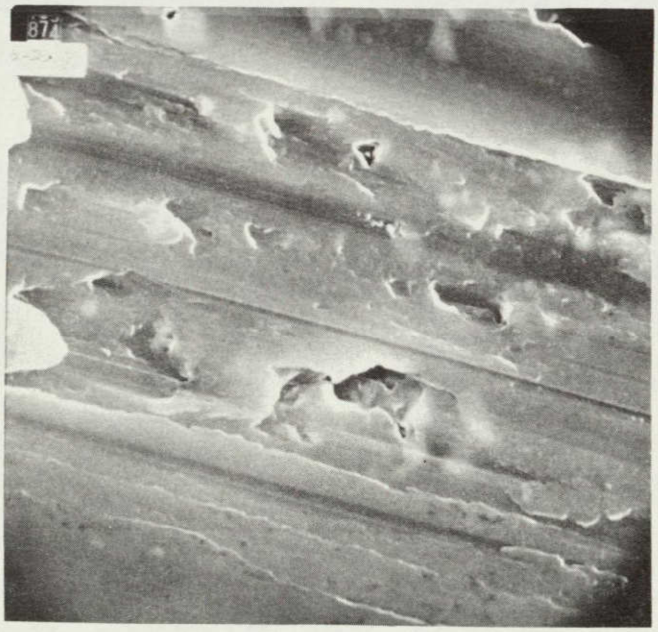
SEM 875 300X

(a)



SEM 876 1000X

(b)



SEM 874 3000X

(c)

Fig. 37 - Scanning Electron Micrographs of Adjacent Surface Away from Abutting Edge; Surface is Acceptable.

Techniques were developed to prepare surfaces without the need for edge manual preparation as specified. However, excess length must be provided for longitudinal welds in cylinders and for welding gore sections in domes, and joint fit-up tolerances may be reduced for a short length in circumferential welds.

An additional length of material must be provided for longitudinal and gore welds because the entire length of such a component cannot be prepared with the device. The need for additional length is governed by the drive unit and location of milling cutters. At the starting end, the abutting surface can be prepared all the way to the end, but adjacent surfaces can be prepared within only about 76.2 mm (3 in.) from the starting end. At the stopping end, the abutting surfaces can be prepared within about 304.8 mm (12 in.), and adjacent surfaces can be prepared within about 228.6 mm (9 in.).

The use of welded start and stop tabs was analyzed as a method for extending the length of components to provide the additional material. At the finish end, use of a 127 mm (5 in.) welded tab to compensate for the length of the drive unit is feasible, but these tabs cannot be mounted with sufficient accuracy to allow for the length of the cutting unit. Therefore, it is recommended that additional length be allowed in the actual part if manual operations are not desired.

When providing additional length in the part, a specified sequence of operations is necessary. The entire length of the abutting surface on the finish end is not completely prepared. Therefore, the entire length of the plate cannot be fit up with an adjacent plate without removing the excess material. To obtain fit-up the following sequence, based on gore sections for a dome, is required (similar sequences would be involved with longitudinal welds in cylinders):

1. Gore section 1: prepare edge to be welded first and cut away one half of the excess material on the finish end corresponding to the prepared side (Figure 38a).

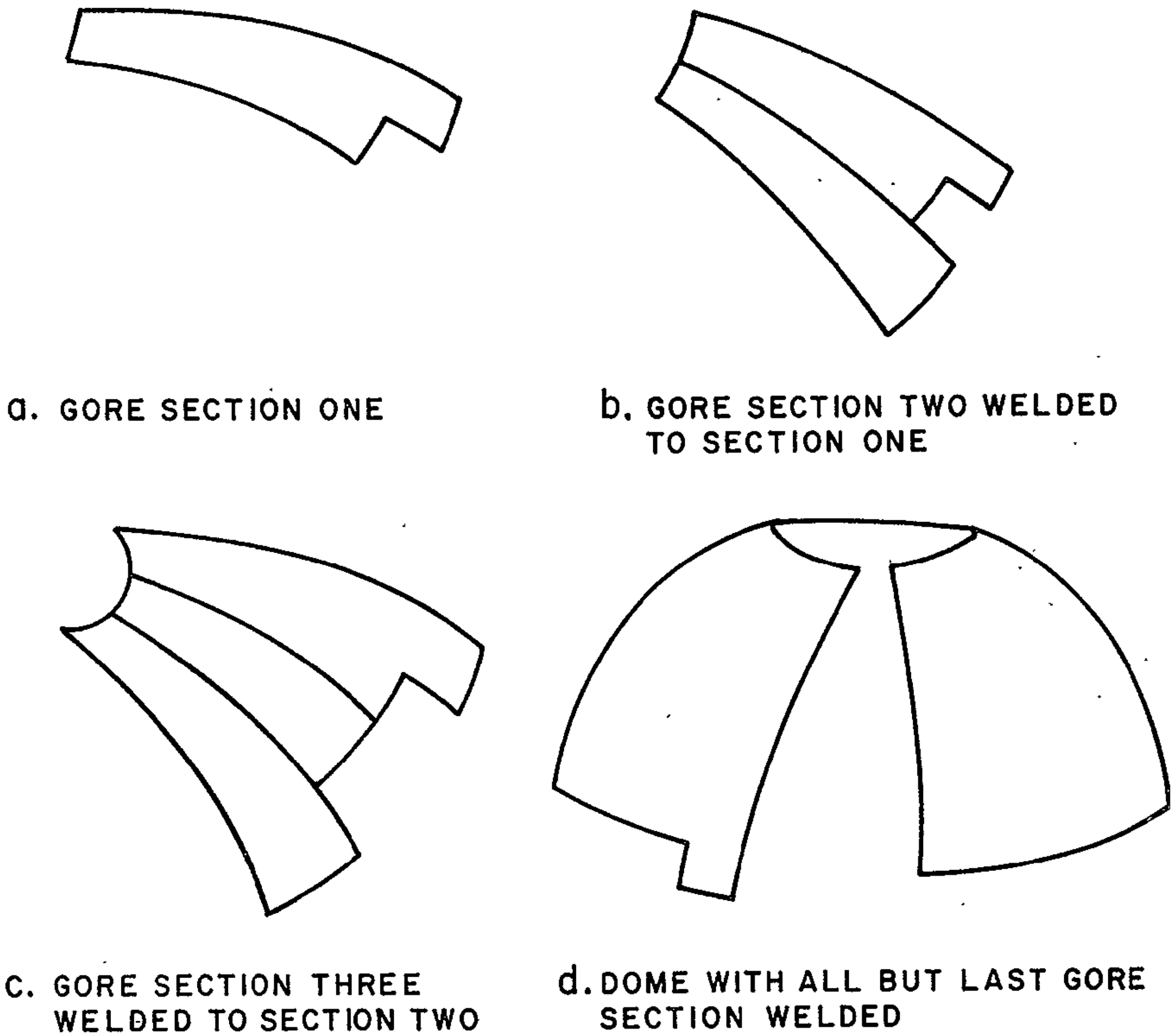



Fig. 38 Schematic Illustration of Sequence for Preparing and Welding Gore Sections to Form Dome

2. Gore section 2: prepare edge to be welded to section 1.
3. Weld gore section 2 to gore section 1 (Fig. 38b).
4. Gore section 2: prepare edge to be welded to gore section 3 and cut away additional metal.
5. Gore section 3: prepare edge to be welded to gore section 2.
6. Weld gore section 3 to gore section 2 (Fig. 38c).
7. Gore section 3: prepare edge to be welded to gore section 4 and cut away additional material.
8. Repeat sequence outlined for sections 2 and 3 for remaining sections up to the last gore section.
9. Last gore section: prepare both surfaces; cut away additional metal; prepare edge of gore section; remove additional material; and deposit both welds in the dome.

The sequence above provides two important advantages: manual work on the prepared surfaces is not necessary, and the surfaces are prepared immediately before welding. An alternate sequence is to prepare both surfaces of each gore section and remove the additional metal prior to placing it in the welding fixture. The major disadvantage with the alternate sequence is the increased possibility of contaminating the second edge before welding.

A third alternative, which does require manual work on the surfaces, is to scrape the areas that are not machined with the device. Under the worst conditions, 304.8 mm (12 in.) of abutting edge at the finish end and 76.2 mm (3 in.) and 228.6 mm (9 in.) of adjacent surface at the start and finish ends, respectively, would be manually prepared.

When preparing circumferential surfaces in cylinders, the unit returns to a previously prepared edge. Because the device controls depth of cut by rollers which roll on the plate edge and thrust buttons which contact the adjacent surfaces, dimensional variations must be acceptable or manual surface preparation work is required to completely prepare the surface.

There are four alternate sequences for stopping the device on circumferential surfaces, one of which does not require manual work. The first is to let the unit return completely so that the cutting unit rests entirely on previously prepared surfaces before stopping. Theoretically, this sequence will result in a surface with the contour shown in Figure 39a when cutting with a 0.0762 mm (0.003 in.) depth of cut on all surfaces. The variations theoretically occur, first as the forward horizontal roller contacts the previously prepared edge (Figure 40a). At that time the vertical cutter is raised as the forward end of the cutting unit drops and the depth of cut on the edge is reduced. The other changes occur as the aft horizontal roller and thrust buttons contact the previously prepared surfaces (Figure 40b). At this time, the aft end of the cutting unit drops, causing an increased depth of cut on the edge and the horizontal cutters move in causing an increased depth of cut on the adjacent surfaces.

Tests were performed to evaluate this first technique, which allows all of the surface to be prepared without manual operations. In actual tests with a 0.762 mm (0.003 in.) depth of cut, the variation on the abutting surfaces could not be measured when two parts, one flat and the other finished in the prescribed manner, were placed in contact. Therefore, the calculated changes shown in Figure 39a do not hold true in tests. The change in thickness was measurable with a micrometer. Cut depths of 2.54 mm (0.010 in.) were required to measure the variation of the abutting edges by placing two parts together.

The second technique is to stop the device just before the aft roller contacts the previously prepared surface resulting in the contour shown in Figure 39b. With this technique about 50.8 mm (2.0 in.) of the abutting edge and 76.2 mm (3.0 in.) of adjacent surfaces are not prepared and must be manually prepared.

The third technique is to stop the device before the forward horizontal rolls on the cutting unit contact the previously

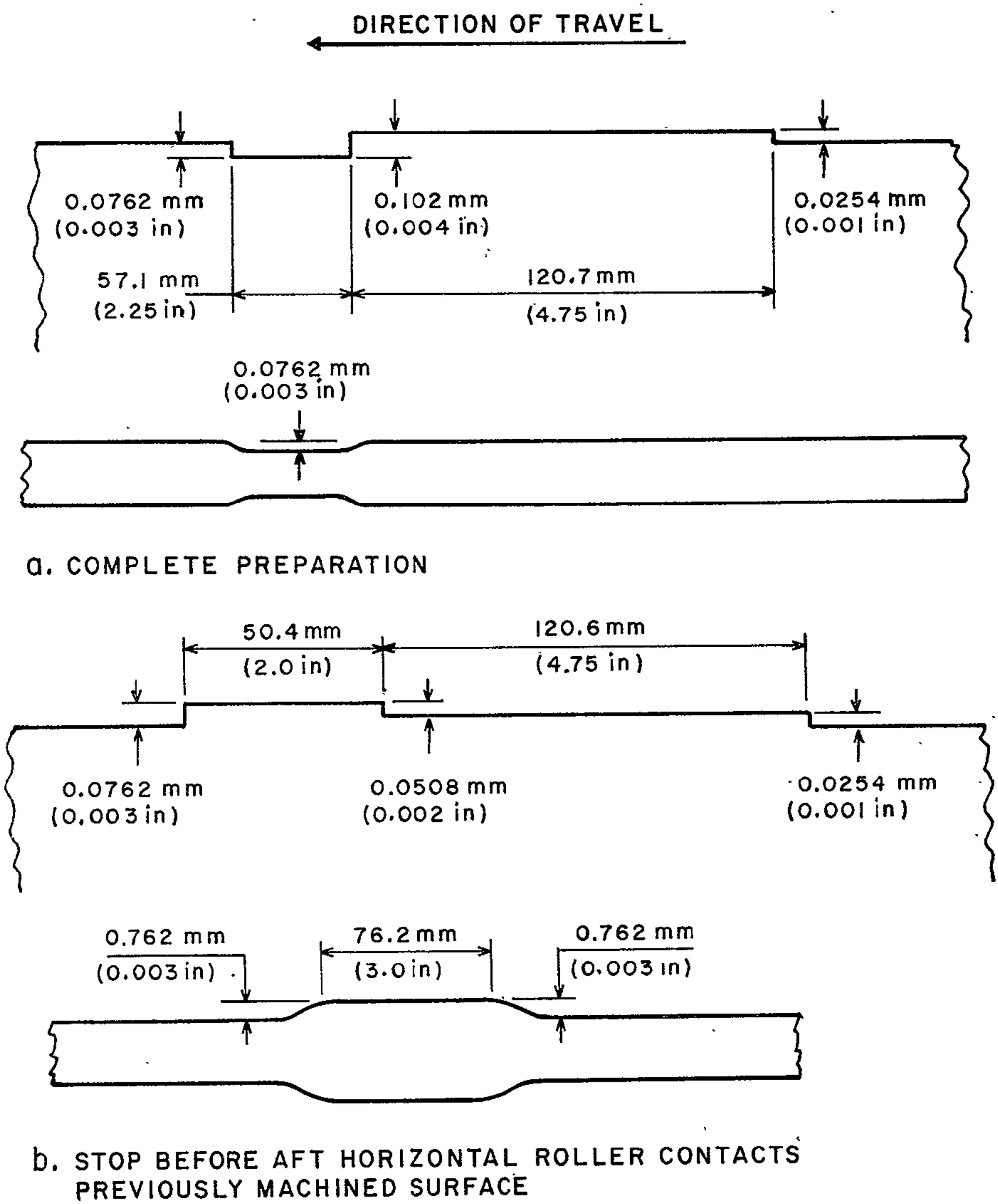
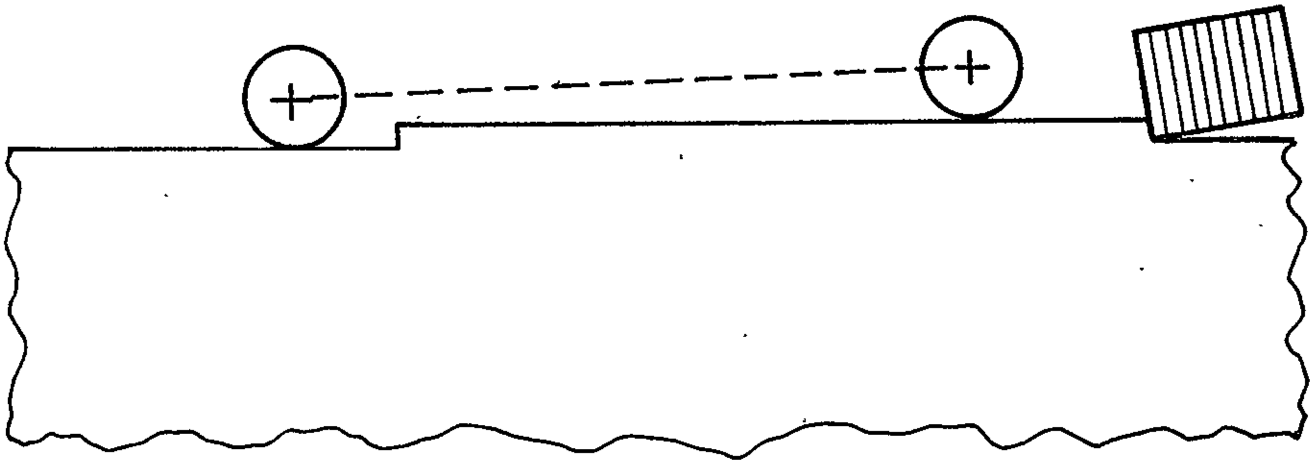
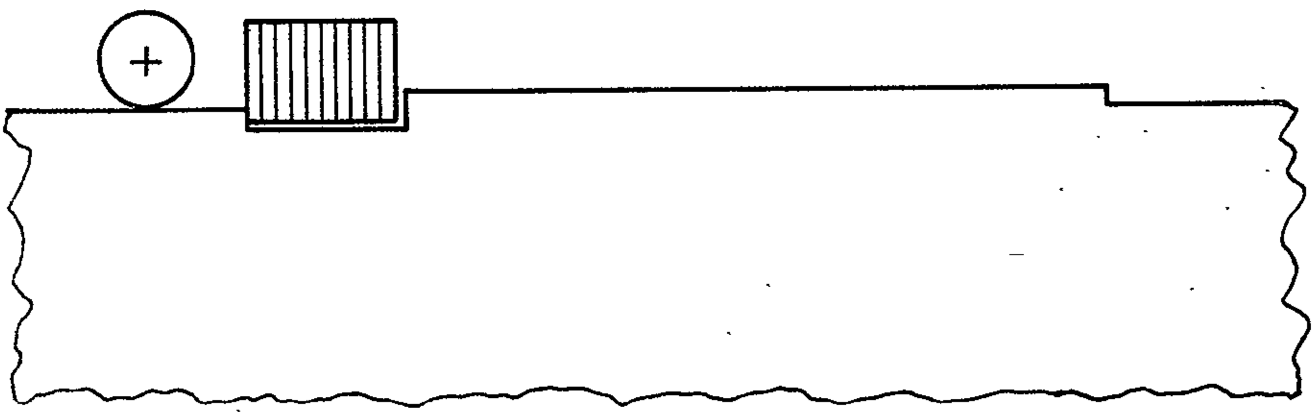



Fig. 39 Theoretical Surface Controus Achieved in Circumferential Surfaces with Different Stop Locations



a. FRONT ROLLER CONTACTS PREVIOUSLY PREPARED SURFACE



b. AFT ROLLER CONTACTS PREVIOUSLY PREPARED SURFACE

Fig. 40 Theoretical Effects as Cutting Unit Returns to Previously Prepared Surface

prepared surface. This technique requires manual surface preparation of about 177.8 mm (7 in.) of both adjacent surfaces and abutting edge.

The last technique is to place a strip of shim stock, equivalent in thickness to the depth of cut, on the abutting surface for the horizontal rolls to ride on as they reach the location of the previously prepared surface. Limited success was achieved with this technique in the evaluation. The shim stock was placed on the edge as a long strip and was manually held from one end. The results appear promising, but additional tests should be performed on simulated parts.

### 8. Waviness of Edge and Surface Defects

Machining parameters and the design of the device were selected to minimize defects in the surface which might contribute to weld defects. Proper use of the device will not cause burrs, nicks, gouges, grooves, surface burning, or undercuts. However, if the surface to be prepared has excess waviness, the prepared surface also will exhibit the same characteristics. Likewise, if the original surface contains large nicks, grooves and gouges, they will be reduced by the device, but will not be eliminated.

## V. SUMMARY AND CONCLUSIONS

A practical system for preparing the welding surfaces of aluminum components was developed and demonstrated. The system consists of dry milling the abutting edges and adjacent surfaces of aluminum to remove contaminated surface layers and expose a fresh surface with a low defect potential. A prototype device was designed and fabricated to demonstrate the feasibility of the system.

The prototype device is designed to straddle the edge that is being prepared and to align with the existing edge and adjacent surfaces of the component. Depth of cut is regulated from

the existing surfaces. Therefore, reasonably smooth existing surfaces and a uniform thickness are required on the component that is being prepared.

The device is equipped with an electric drive unit to provide travel and three air-operated milling motors to provide the required machining operations. The drive unit provides a mechanized uniform travel speed. The milling motors are aligned to machine the abutting edges and adjacent surfaces simultaneously.

The prototype device was used to prepare the weld surfaces of flat and curved aluminum plates with a square butt weld joint configuration. These surfaces were evaluated on the bases of gas tungsten-arc spot and seam weld soundness, Proficorder measurements, and scanning electron microscopy. Results from these evaluations proved the technique, system, and prototype device to be satisfactory for the intended application.

## VI RECOMMENDATIONS FOR FUTURE WORK

Additional studies to provide a comprehensive evaluation of the device and to determine areas for improvement are recommended. These studies should be performed on simulated or experimental parts for which a background of knowledge on joint fit-up requirements and in the incidence of repairable weld defects has been developed. The studies should be performed to:

1. Determine the extent to which repairable defects can be eliminated by use of the device.
2. Determine the tolerance of the device for parts with varying radii without changes in settings.
3. Determine the fit-up of joints prepared with the device for comparison with the fit-up achieved with manually prepared surfaces.
4. Determine optimum methods for preparing the entire weld surfaces of circumferential joints in cylinders.

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